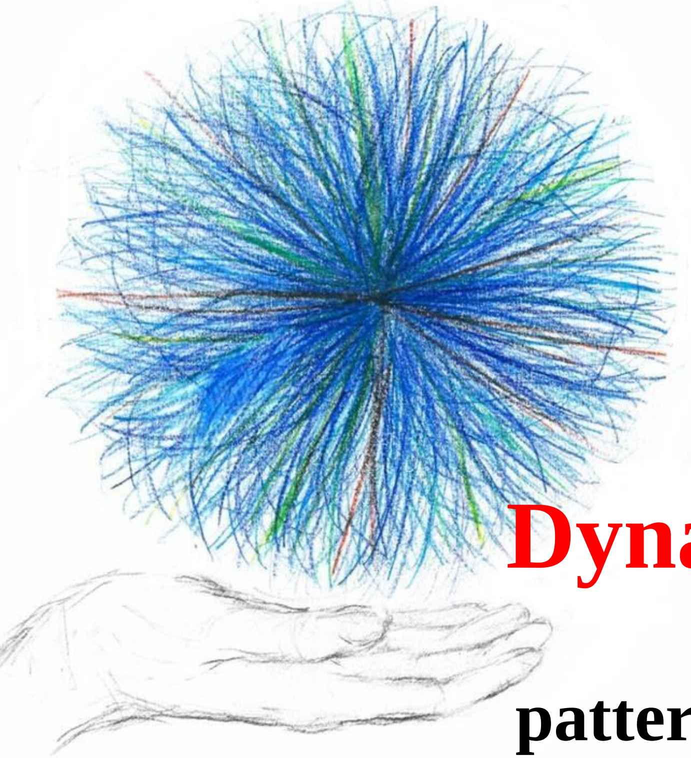

Dynamical energy loss formalism:

from explaining unexpected suppression patterns to implications for future experiments

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European Research Council

МИНИСТАРСТВО ПРОСВЕТЕ, НАУКЕ И ТЕХНОЛОШКОГ РАЗВОЈА

Motivation

- **Energy loss of high-pt particles traversing QCD medium is an excellent probe of QGP properties.**
- **Theoretical predictions can be compared with a wide range of data, coming from different experiments, collision systems, collision energies, centralities, observables…**
- **Can be used together with low-pt theory and experiments to study the properties of created QCD medium, i.e. for precision QGP tomography.**

The dynamical energy loss formalism

- **Finite size medium of dynamical (moving) partons**
- **Based on finite T field theory and HTL approach**

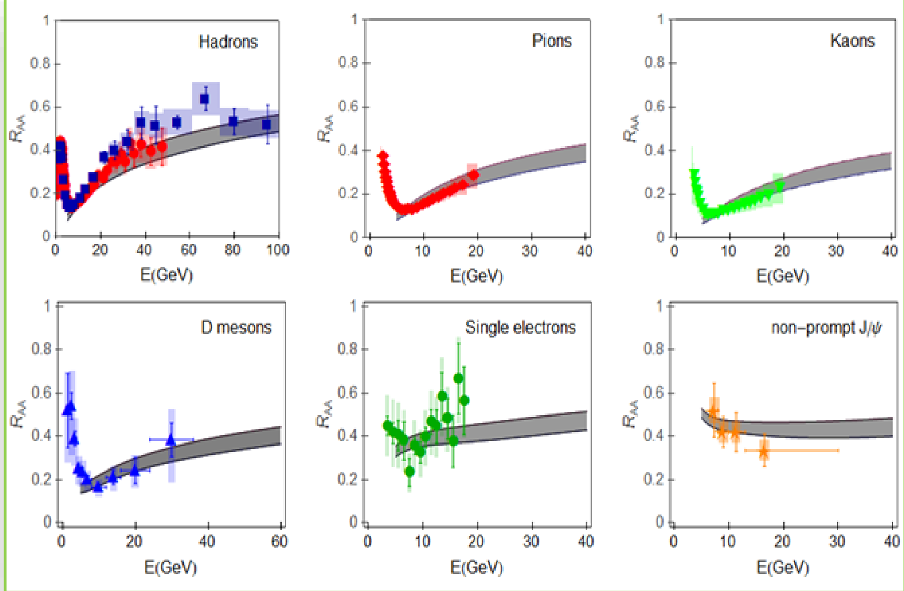
M. D., PRC74 (2006), PRC 80 (2009), M. D. and U. Heinz, PRL 101 (2008).

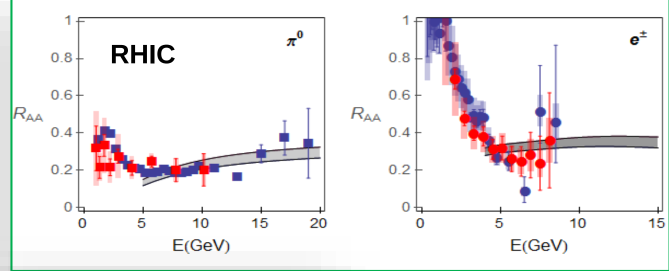
Includes:

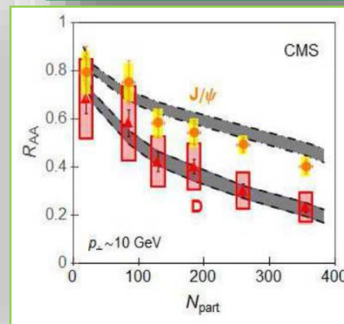
- **Same theoretical framework for both radiative and collisional energy loss**
- **Finite magnetic mass effects (M. D. and M. Djordjevic, PLB 709:229 (2012))**
- **Running coupling (M. D. and M. Djordjevic, PLB 734, 286 (2014)).**
- **Most recently: Relaxed soft-gluon approximation (B. Blagojevic, M.D. and M. Djordjevic, arXiv:1804.07593; B. Blagojevic, Poster: JET-05)**

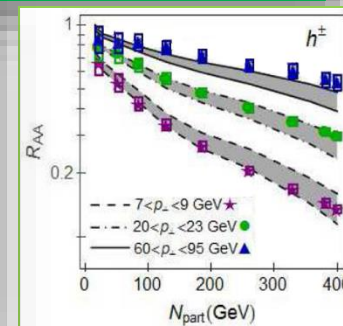
Integrated in a numerical procedure including parton production, fragmentation functions, path-length and multi-gluon fluctuations

- **No fitting parameters**
- **Treats both light and heavy flavor partons**









- Explains R_{AA} 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.
- All steps in the suppression scheme are important, and have to be kept in all future framework developments.

A realistic description parton-medium interactions.

However, the model does *not* include QGP evolution.

So far, predictions only for the observables weakly sensitive to QGP evolution (i.e. R_{AA}).

Goals

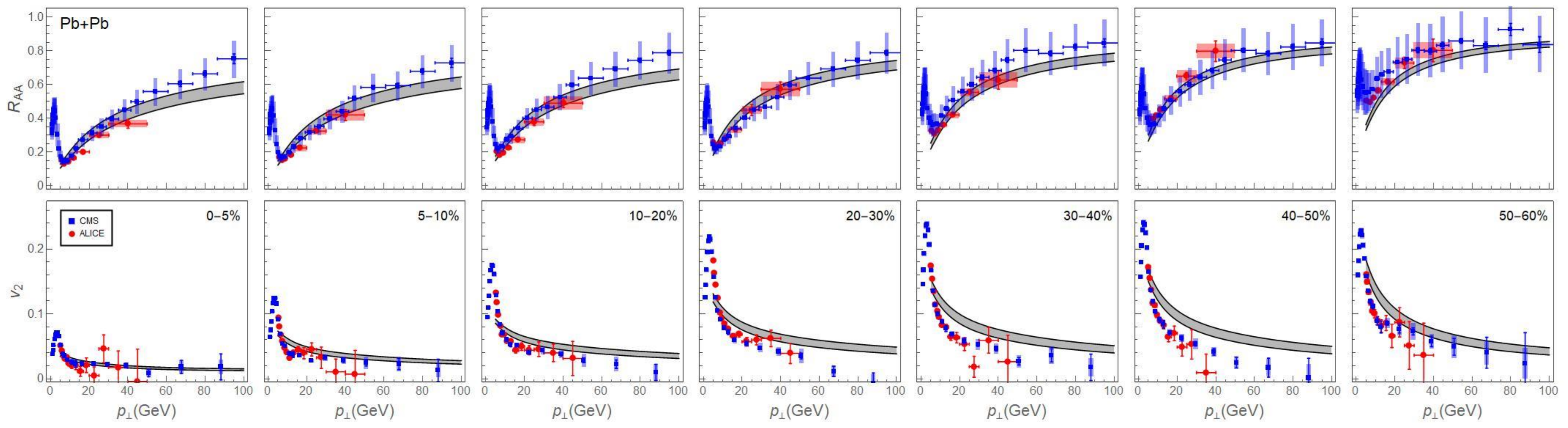
- **Allow systematic comparison of experimental data and theoretical predictions, obtained by the same formalism and the same parameter set. In particular:**
  - **For different observables (both R_{AA} and v_2)**
  - **Different collision systems (Pb+Pb and Xe+Xe)**
  - **Different probes (light and heavy)**
  - **Different collision energies**
  - **Different centralities**
- **Introduce medium evolution in the model, for now through Bjorken expansion.**
- **Differentiate between different energy loss models**
  - **What is an appropriate observable to assess energy loss path-length dependence?**

DREENA-C

DREENA (Dynamical Radiative and Elastic ENergy loss Approach) is a computational framework in which dynamical energy loss is implemented.

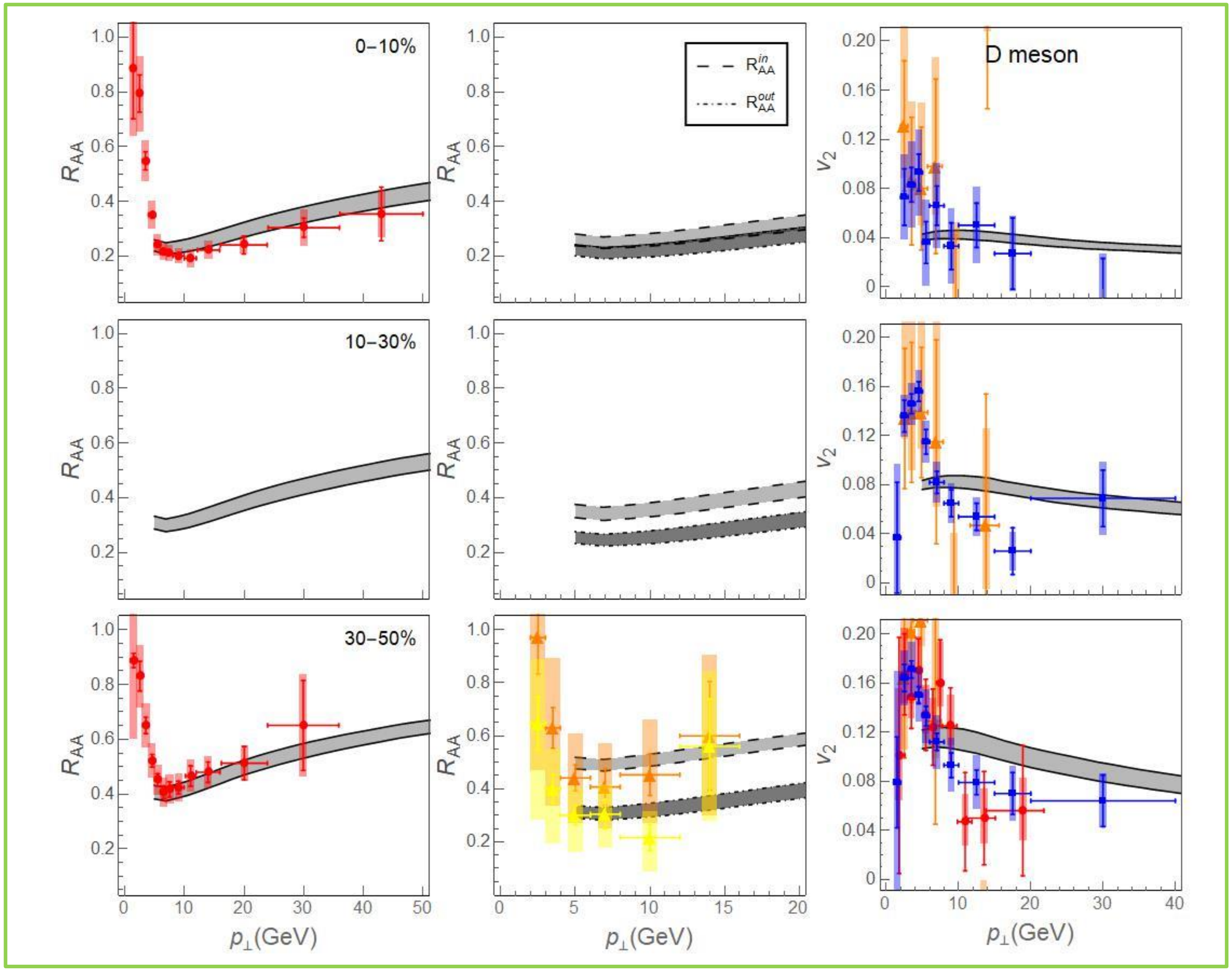
Version C – Constant temperature medium

D. Zigic, I. Salom, J. Auvinen, M. Djordjevic and M.D., arXiv:1805.03494



For charged hadrons, qualitatively good agreement, but overestimation of v_2 data.

D. Zigic, I. Salom, J. Auvinen, M. Djordjevic and M.D., arXiv:1805.03494



ALICE and CMS data

For D mesons, qualitatively good agreement, but again overestimation of v_2 data.

The theoretical models up-to-now, faced difficulties in jointly explaining R_{AA} and v_2 data, i.e. lead to under-prediction of v_2, so called v_2 puzzle.

Overestimation of v_2, obtained by DREENA-C, seems surprising.

However, by using a simple scaling arguments: $\Delta E/E \sim T^a L^b$, where $a, b \rightarrow 1$, in our model, we obtain:

In const T medium:

$$R_{AA} \approx (1 - \xi\, T\, L), \quad v_2 \approx \frac{\xi\, T\, \Delta L}{2}$$

In evolving medium:

$$R_{AA} \approx (1 - \xi\, T\, L), \quad v_2 \approx \frac{\xi\, T\, \Delta L - \xi\, \Delta T\, L}{2}$$

Introduction of medium evolution in our model, should lower the v_2 predictions.

Is this really so?

D. Zigic, I. Salom, J. Auvinen, M. Djordjevic and M.D., arXiv:1805.03494

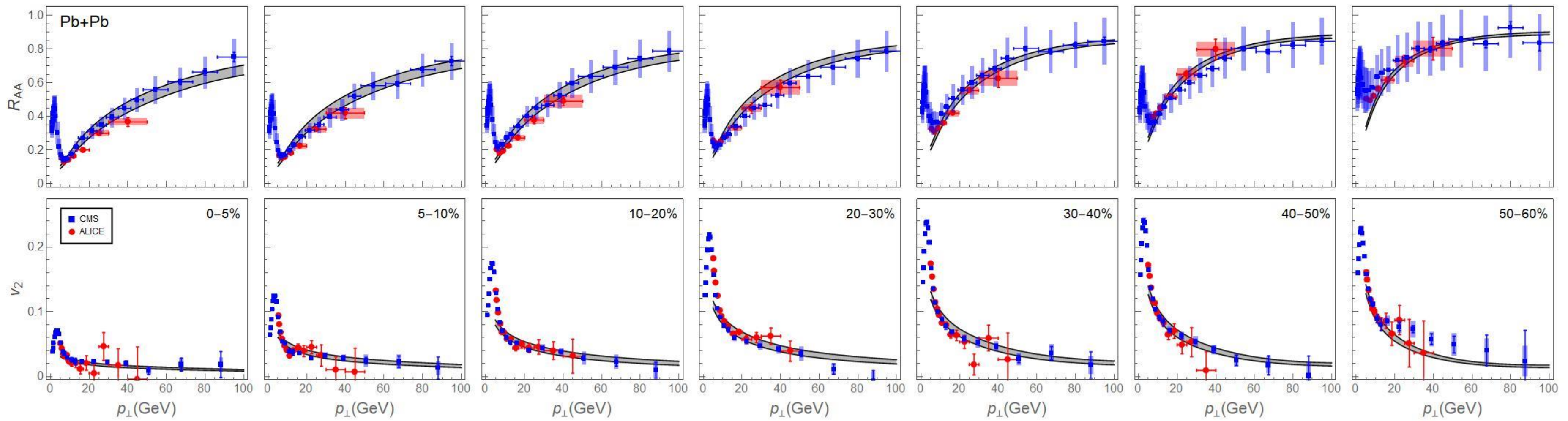
DREENA-B

To check this, we introduce DREENA-B framework.

Version B – 1+1D Bjorken expansion. i.e. medium evolution introduced in a simple analytic way.

First joint R_{AA} and v_2 predictions with dynamical energy loss formalism in expanding QCD medium:

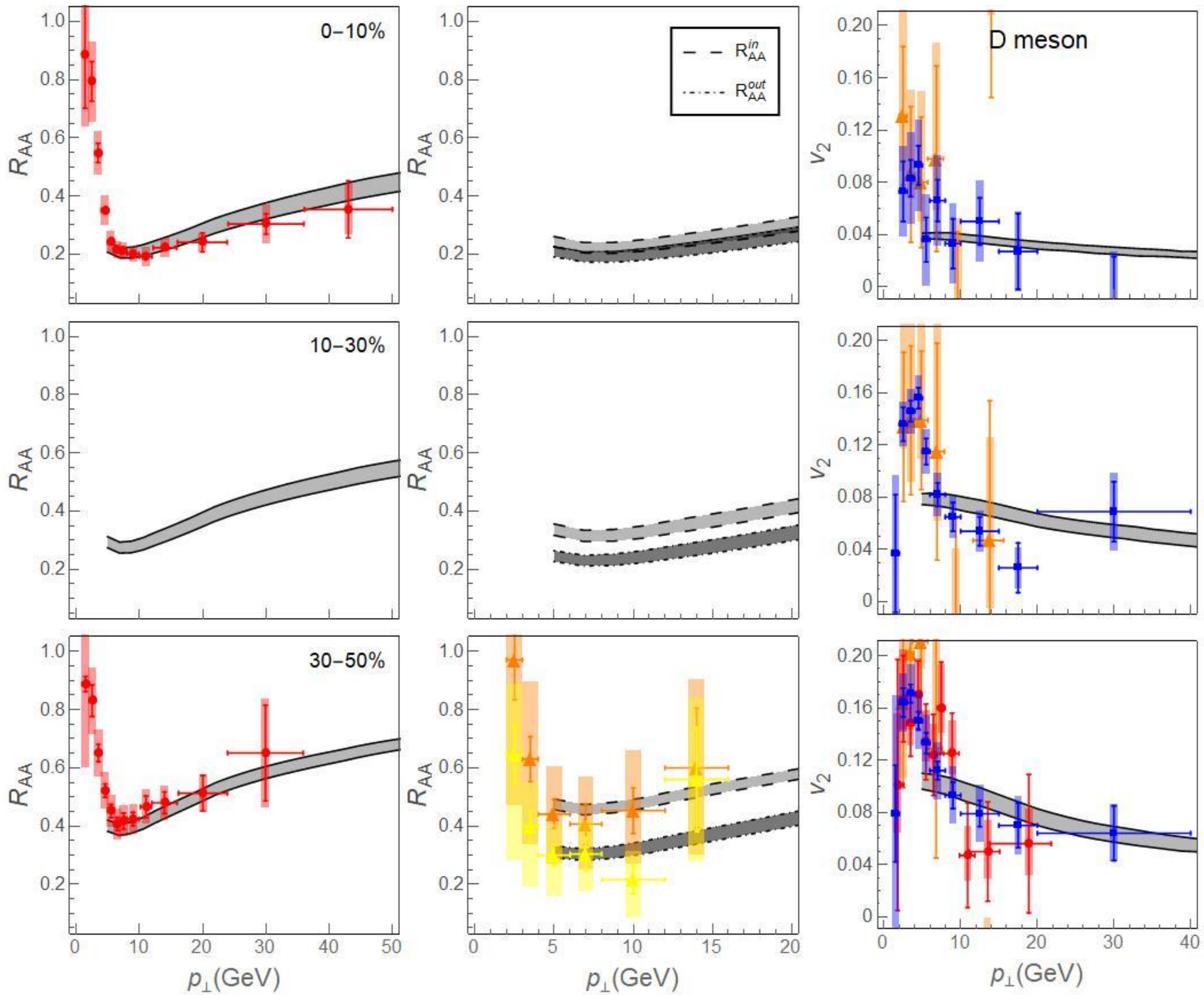
D. Zigic, I. Salom, M. Djordjevic and M.D., arXiv:1805. 04786



ALICE and CMS data

Very good joint agreement with R_{AA} and v_2 data!

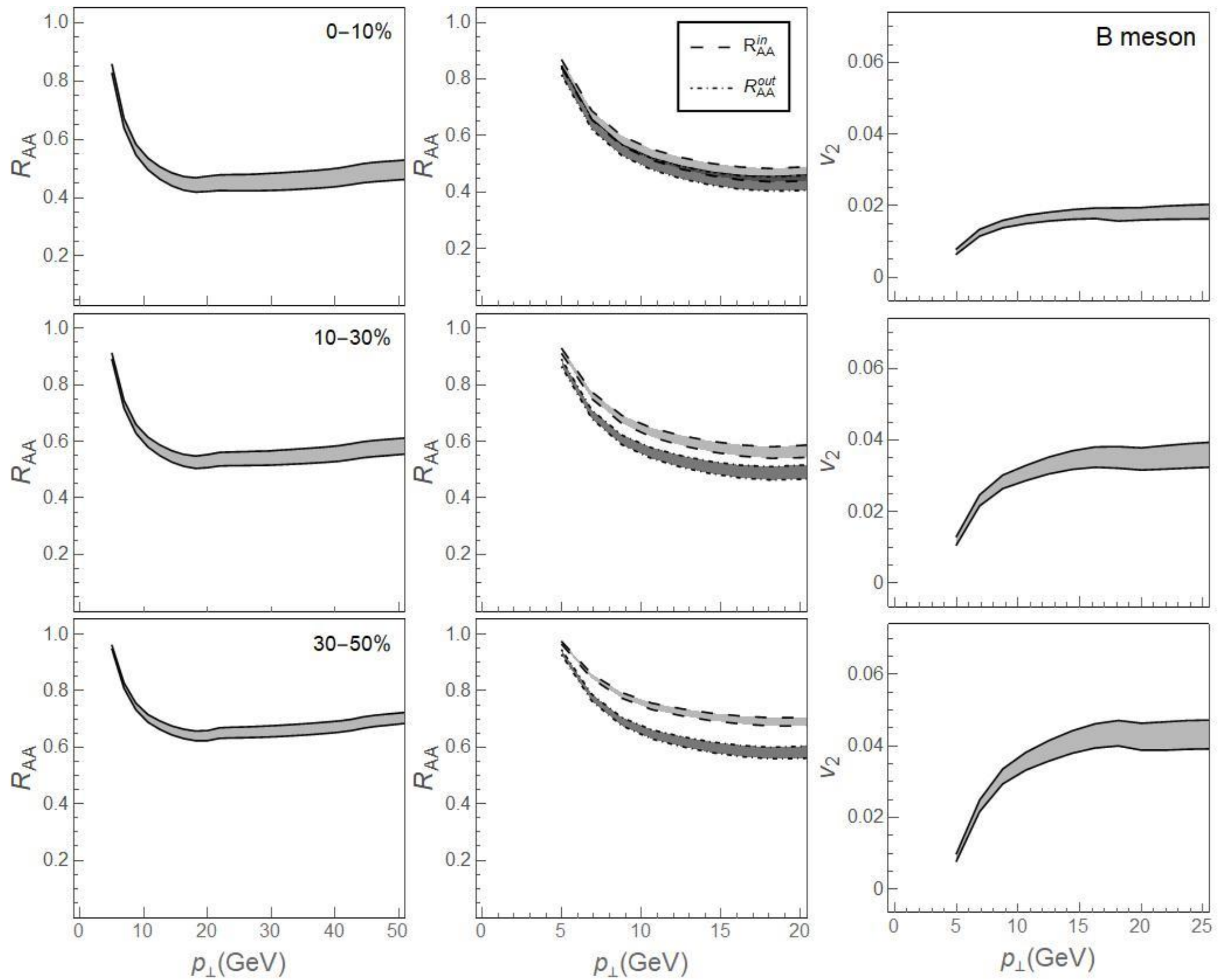
D. Zigic, I. Salom, M. Djordjevic and M.D., arXiv:1805. 04786



ALICE and CMS data

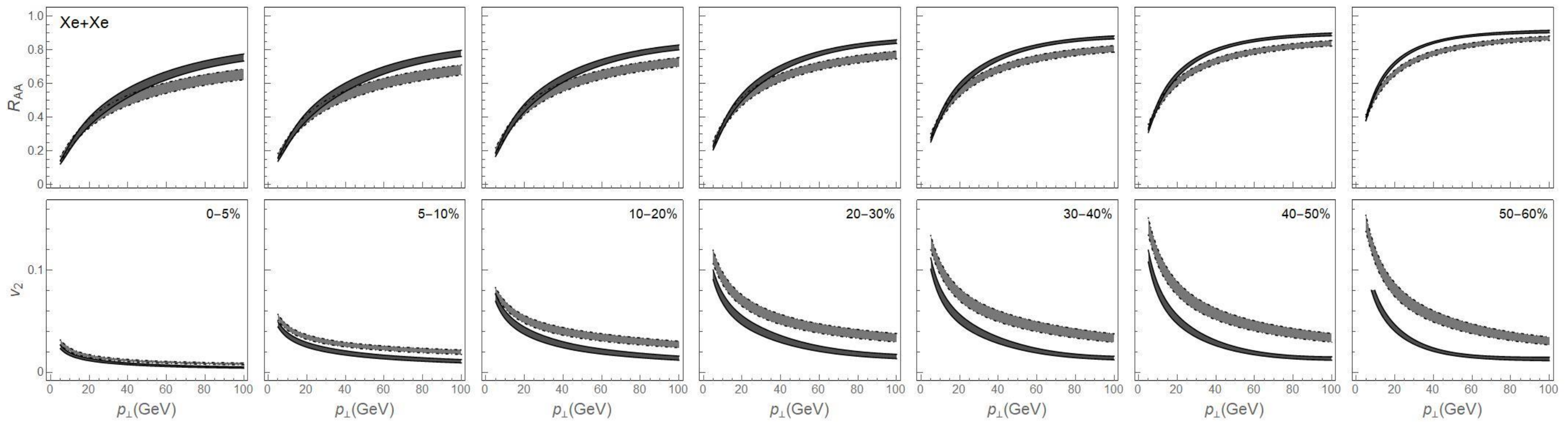
Good joint agreement for D mesons as well!

D. Zigic, I. Salom, M. Djordjevic and M.D., arXiv:1805. 04786



We predict non-zero v_2 for high pt B mesons.

5.44 TeV Xe+Xe predictions with DREENA-C and DREENA-B frameworks



D. Zigic, I. Salom, M. Djordjevic and M.D., arXiv:1805. 04786

Inclusion of medium evolution has effect on both R_{AA} and v_2.

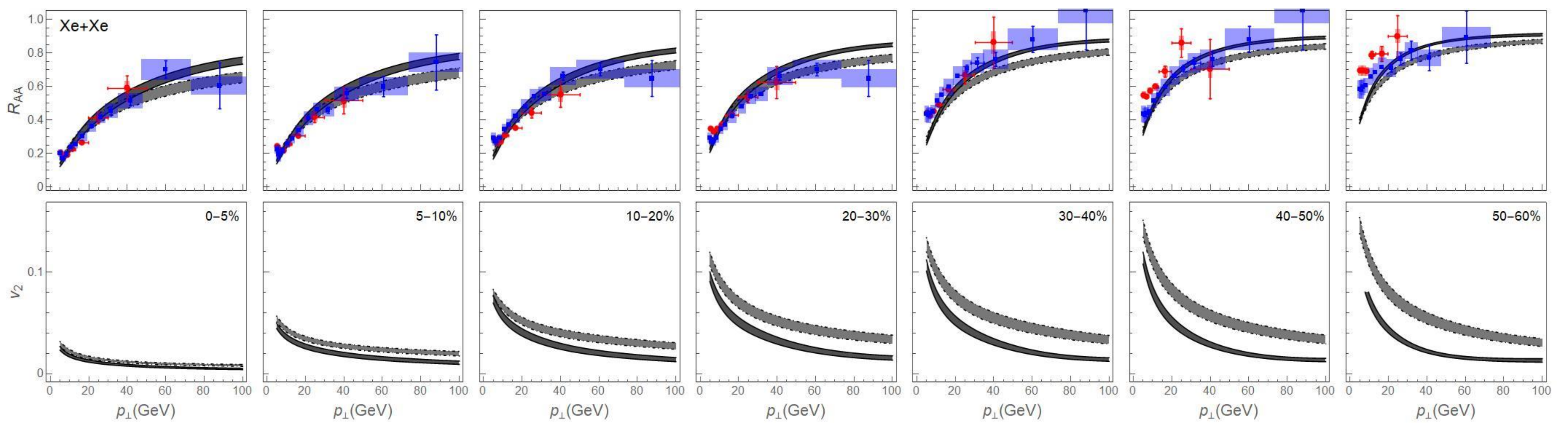
It systematically somewhat increase R_{AA}, while significantly decreasing v_2.

This effect has large influence on v_2 predictions, confirming previous observations that v_2 observable is sensitive to medium evolution.

This effect is rather small on R_{AA}. However, for precise predictions, it should not be neglected in precise R_{AA} calculations.

5.44 TeV Xe+Xe predictions with DREENA-C and DREENA-B frameworks

ALICE and CMS data



D. Zigic, I. Salom, M. Djordjevic and M.D., arXiv:1805. 04786

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How to differentiate between different energy loss models?

Path length dependence (energy loss ~L^b) straightforwardly differentiates different energy loss models.

- **Many energy loss models have linear (b=1) or quadratic (b=2) path-length dependence.**
- **The dynamical energy loss path-length dependence is between linear and quadratic, due to both collisional and radiative energy loss mechanisms included in the model.**
- **Therefore, the path length dependence provides an excellent signature differentiating between different energy loss models, and consequently also between the underlying energy loss mechanisms.**

What is an appropriate system?

Measurements on 5.02 TeV Pb+Pb already available, 5.44 TeV Xe+Xe are also becoming available.

The main property differentiating the two systems is its size (A_{PbPb}=208, A_{XeXe}=129) .

All other properties basically remain the same:

i. **Initial momentum distribution**

ii. **Average temperature for each centrality region**

iii. **Path length distributions (up to rescaling factor $A^{1/3}$)**

Consequently, comparison of suppressions in Pb+Pb and Xe+Xe is an excellent way to study the path length dependence.

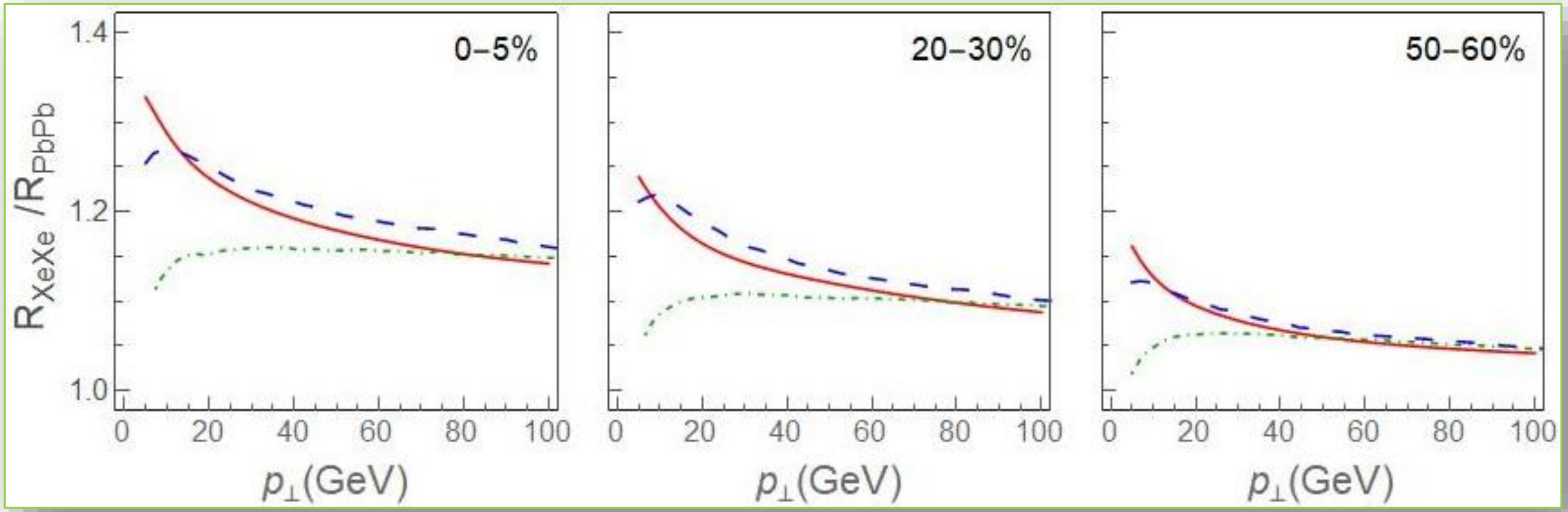
M.D., D. Zigic, M. Djordjevic and J. Auvinen, arXiv:1805.04030

What is appropriate observable?

M.D., D. Zigic, M. Djordjevic and J. Auvinen, arXiv:1805.04030

The ratio of the two R_{AA}s seems a natural choice, and has been proposed before.

However, in this way the path length dependence cannot be naturally extracted (also a strong centrality dependence):



What is the reason for this? – use a simple scaling arguments:

$$\Delta E/E \sim T^a L^b \Longrightarrow \frac{R_{XeXe}}{R_{PbPb}} \approx 1 - \xi T^a L^b_{Pb} \left(1 - \left(\frac{A_{Xe}}{A_{Pb}}\right)^{b/3}\right)$$

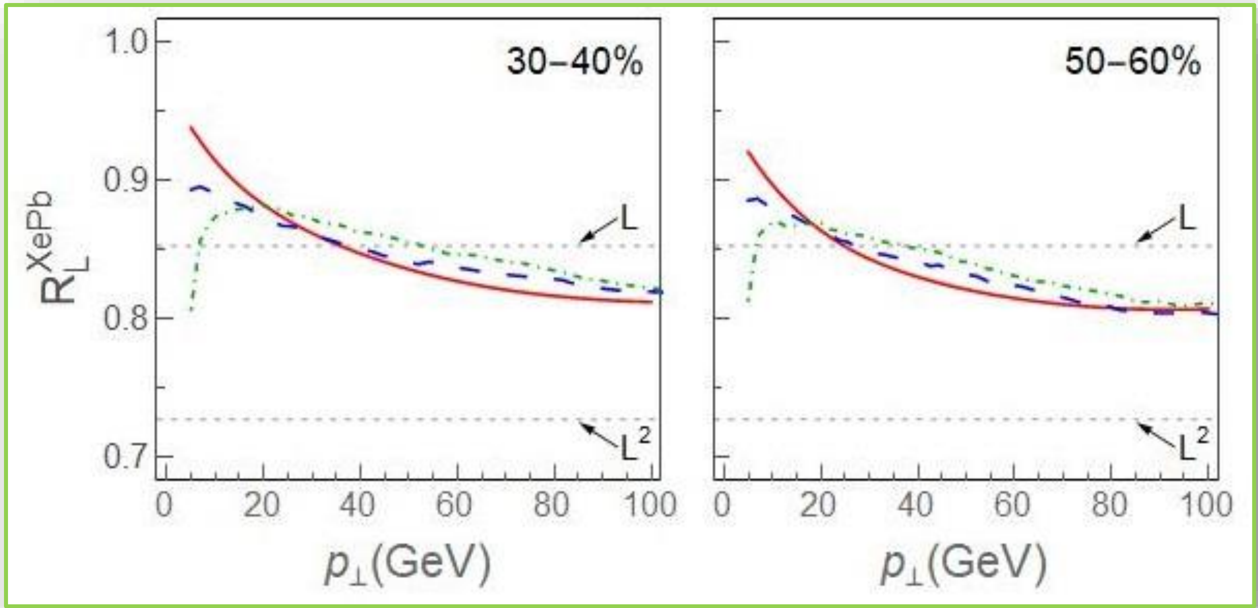
We see that the ratio includes a complicated relationship.

What we propose?

Use 1-R_{AA} ratio instead:

$$R_L^{XePb} \equiv \frac{1 - R_{XeXe}}{1 - R_{PbPb}} \approx \frac{\xi T^a L^b_{Xe}}{\xi T^a L^b_{Pb}} \approx \left(\frac{A_{Xe}}{A_{Pb}}\right)^{b/3}$$

We see a simple dependence on only size of the medium ($A^{1/3}$ ratio) and the path length dependence (exponent b).



M.D., D. Zigic, M. Djordjevic and J. Auvinen, arXiv:1805.04030

The path length dependence can be extracted in a simple way, and there is only a weak centrality dependence.

1-R_{AA} ratio therefore seems as a natural observable, which we call path-length sensitive suppression ratio.

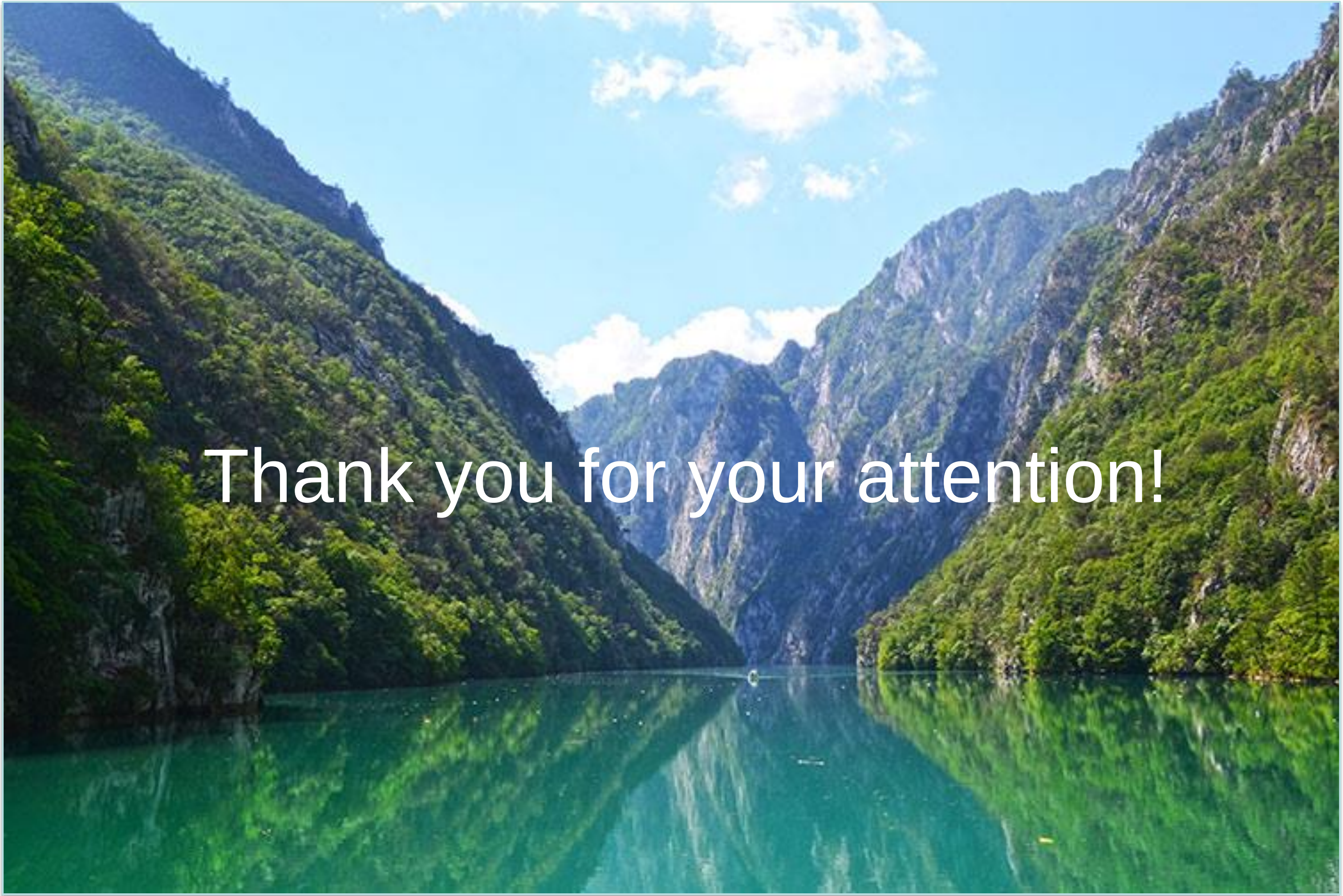
Conclusion

We introduce DREENA-C and DREENA-B frameworks, where DREENA is a computational implementation of the dynamical energy loss formalism.

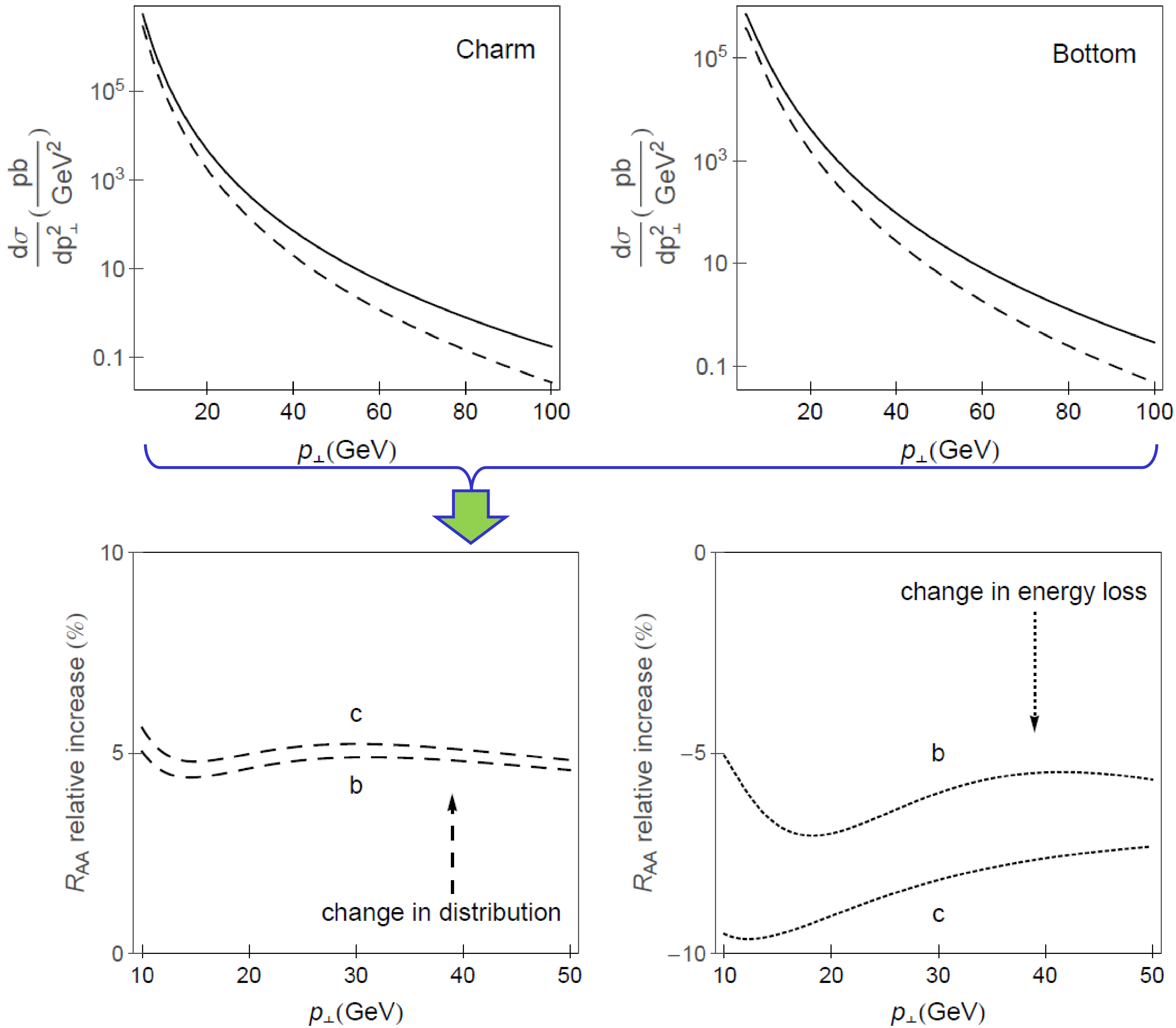
At constant *T* our predictions overestimate v_2. With Bjorken expansion, we have a good agreement with both R_{AA} and v_2 data. Introducing medium evolution has a larger effect on v_2, but for precision predictions it also has to be taken into account for R_{AA}.

We propose a new observable which we call path length sensitive suppression ratio. We also argue that Pb+Pb vs. Xe+Xe measurements make an excellent system to assess the path length dependence.

OUTLOOK: Introduction of more complex medium evolution in the dynamical energy loss formalism can provide a basis for a state of the art QGP tomography tool – e.g. to jointly constrain the medium properties from the point of both high-pt and low-pt data.



Canyon of Serbian river DREENA



Charm
Bottom
$\frac{d\sigma}{dp_\perp^2}\left(\frac{pb}{GeV^2}\right)$
10^5
10^3
10
0.1
20
40
60
80
100
$p_\perp$(GeV)
R_{AA} relative increase (%)
c
b
change in distribution
change in energy loss
$p_\perp$(GeV)

Temperature dependence of the energy loss