

DREENA framework: predictions,
comparison with experimental data,
and proposal of a new observable

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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:

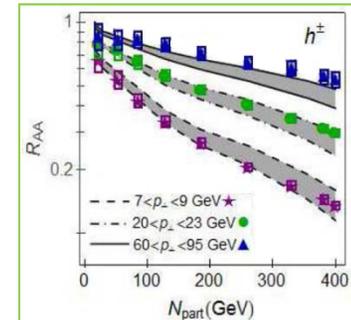
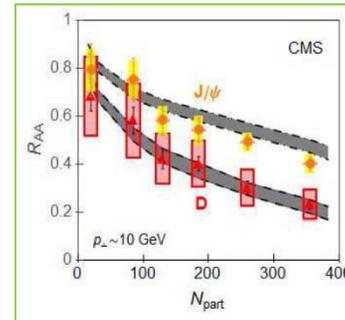
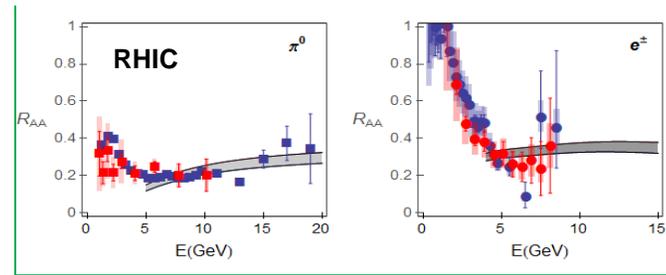
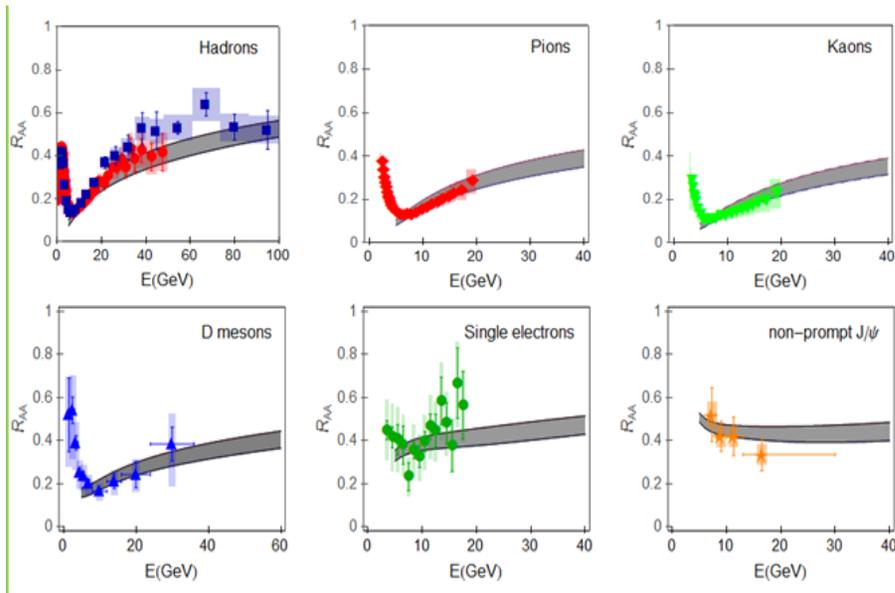
- **Same theoretical framework for both radiative and collisional energy loss**
- **Finite magnetic mass effects (M. D. and M. Djordjevic, PLB 709:229 (2012))**
 - **Running coupling (M. D. and M. Djordjevic, PLB 734, 286 (2014)).**
- **Most recently: Relaxed soft-gluon approximation (B. Blagojevic,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



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

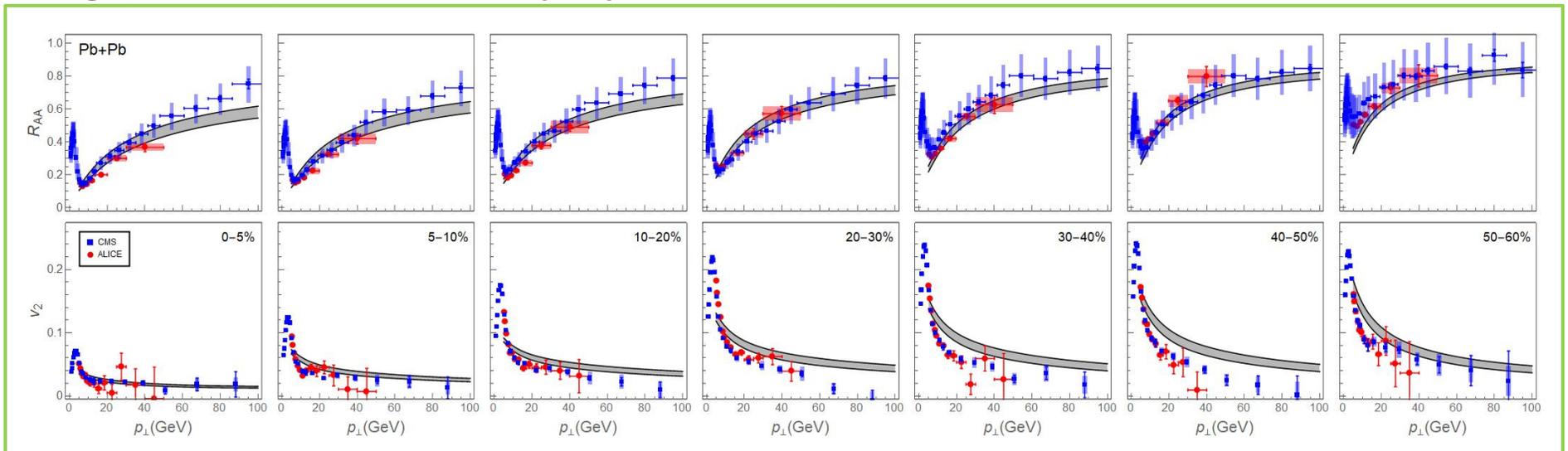
- **Allow systematic comparison of experimental data and theoretical predictions, obtained by the same formalism and the same parameter set. In particular:**
 - For different observables (both R_{AA} and v_2)
 - Different collision systems (Pb+Pb and Xe+Xe)
 - Different probes (light and heavy)
 - Different 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

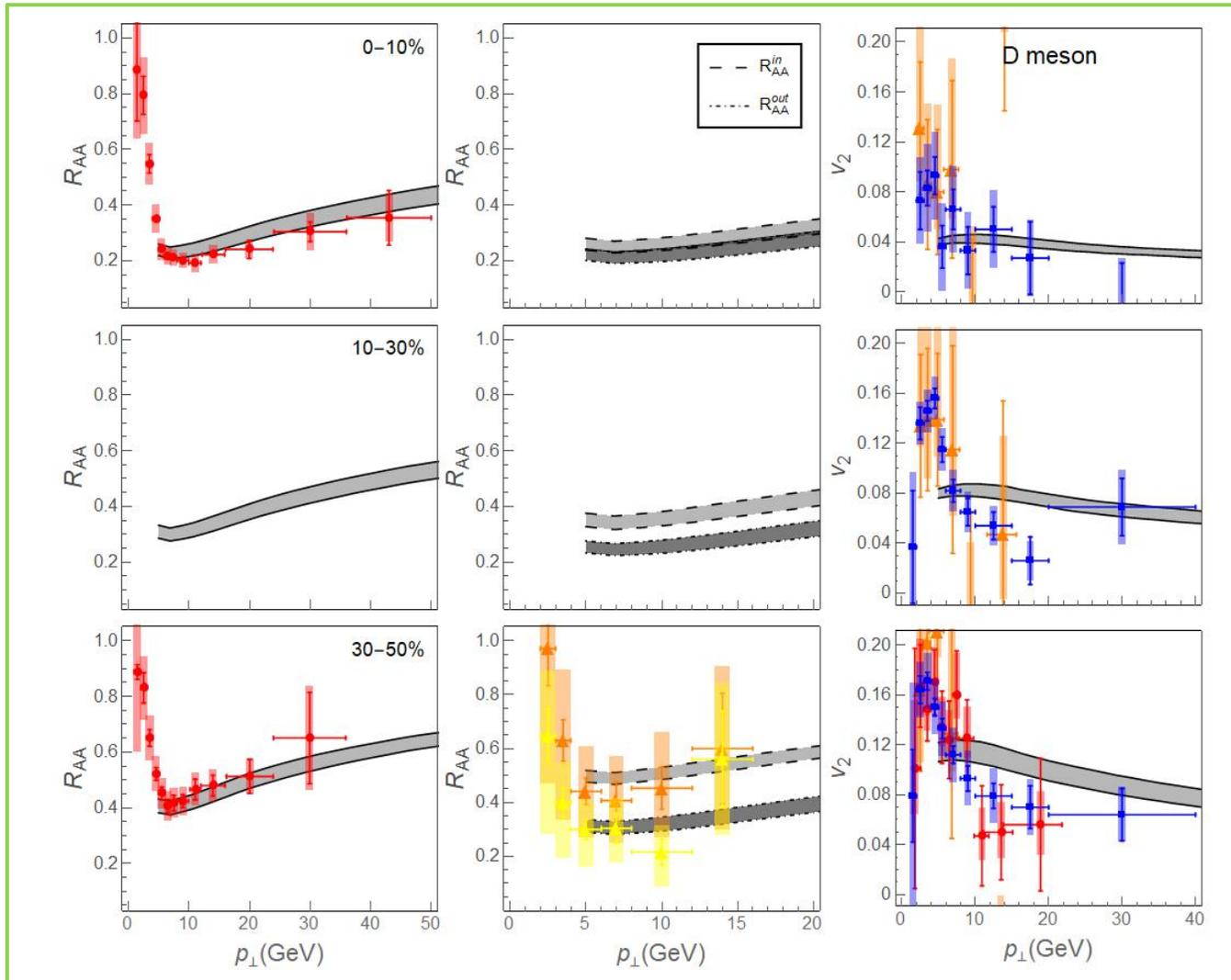
DREENA (**D**ynamical **R**adiative and **E**lastic **E**nergy loss **A**pproach) is a computational framework in which dynamical energy loss is implemented.

Version **C** – **C**onstant 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.



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?

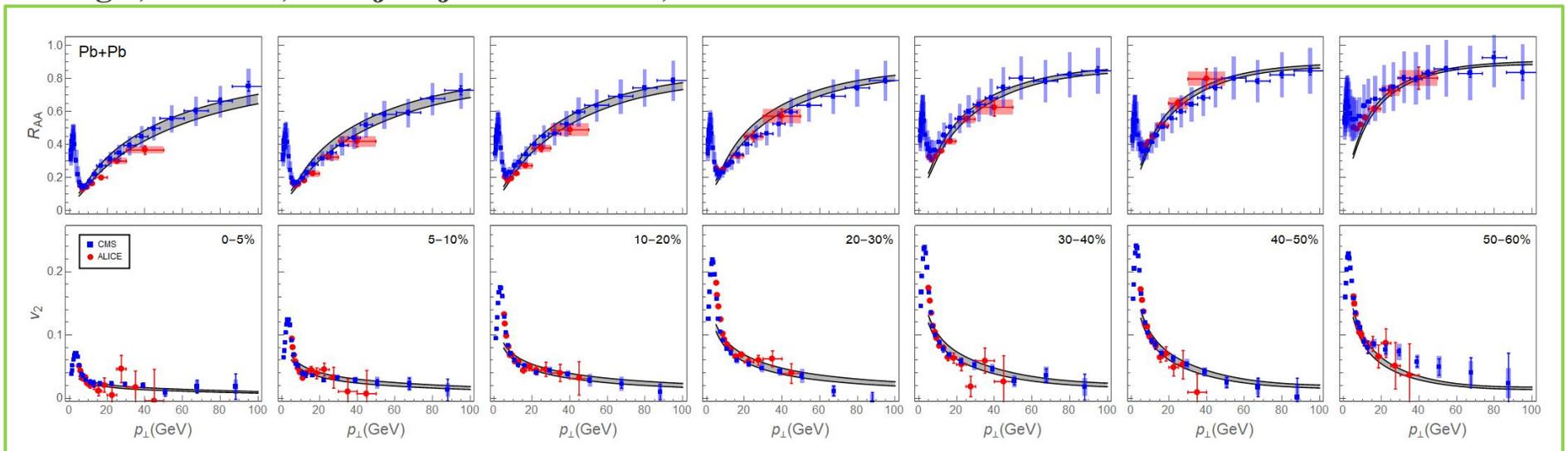
DREENA-B

To check this, we introduce **DREENA-B** framework.

Version **B** – 1+1D **B**jorken 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:

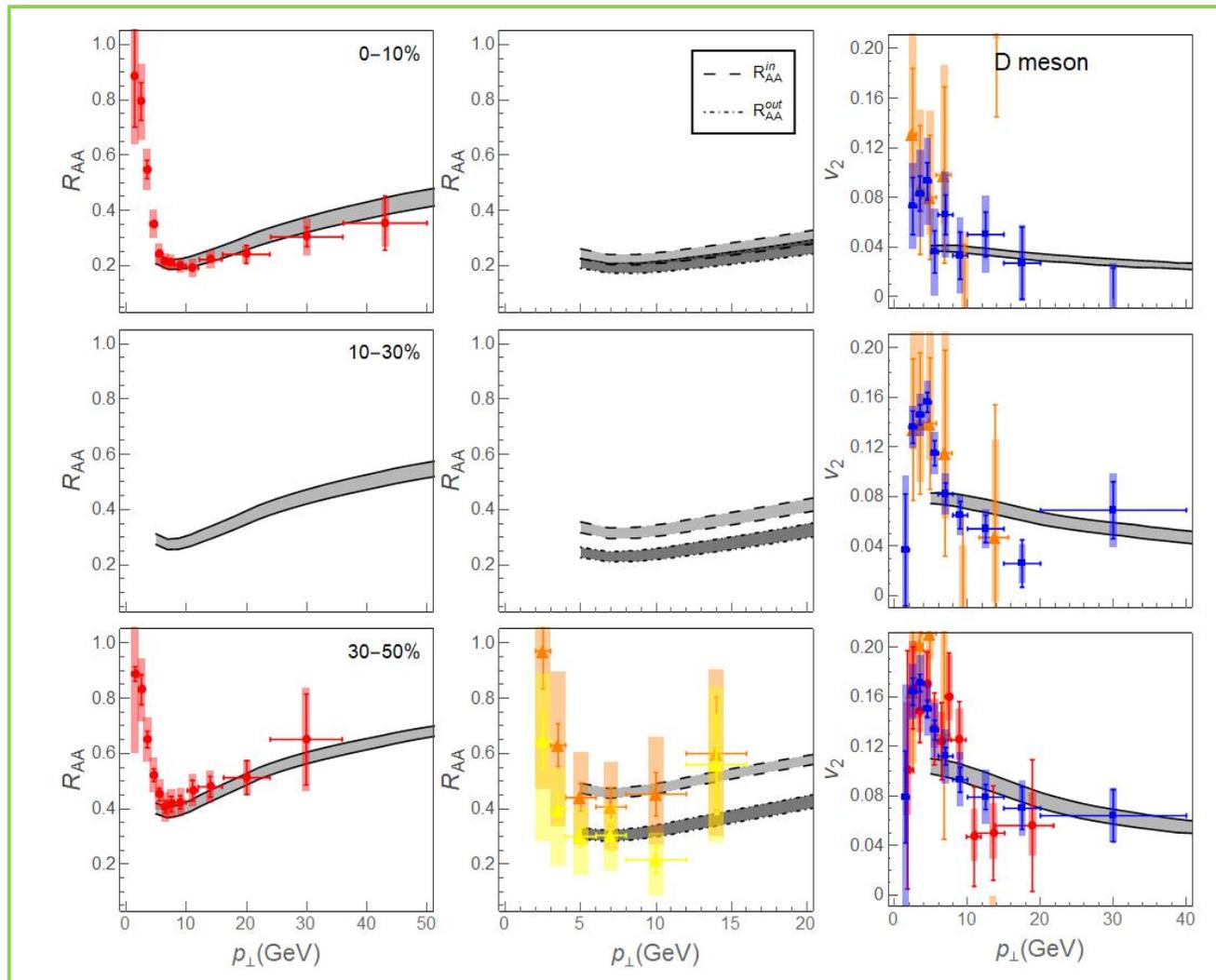
D. Zigic, I. Salom, M. Djordjevic and M.D., arXiv:1805.04786



ALICE and CMS data



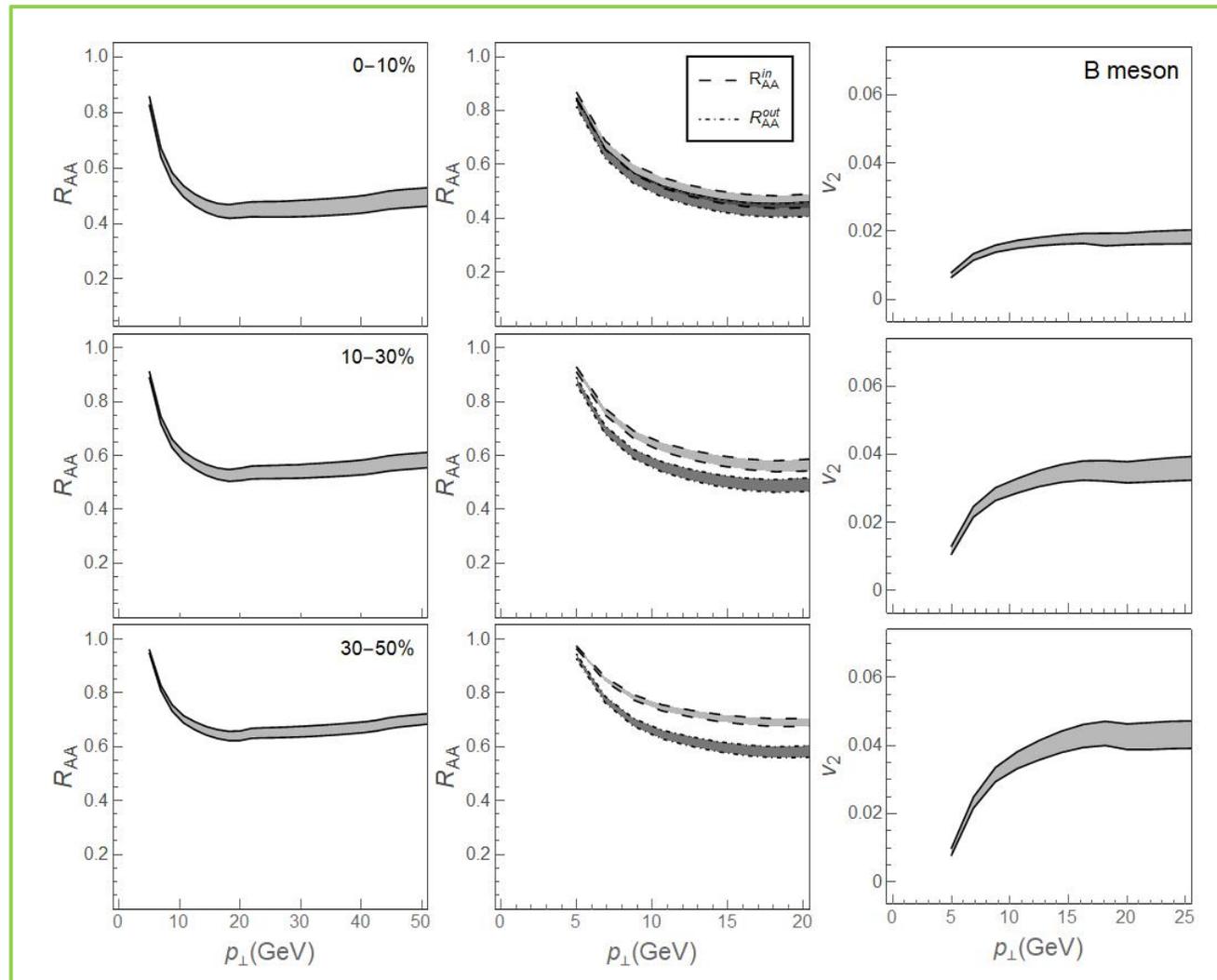
Very good joint agreement with R_{AA} and v_2 data!



ALICE and CMS data

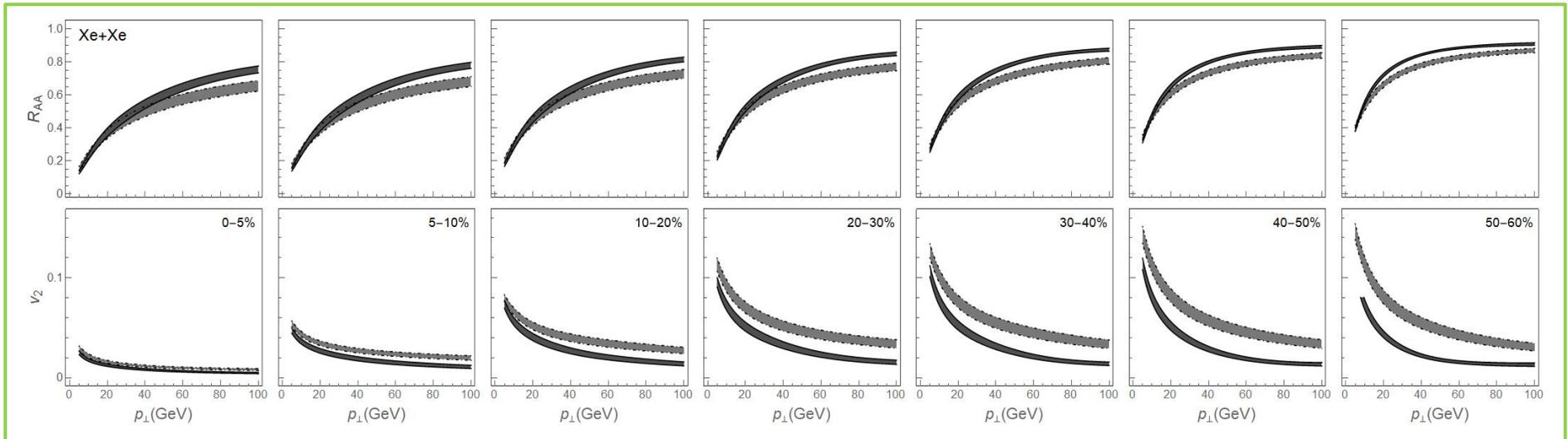


Good joint agreement for D mesons as well!



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 .

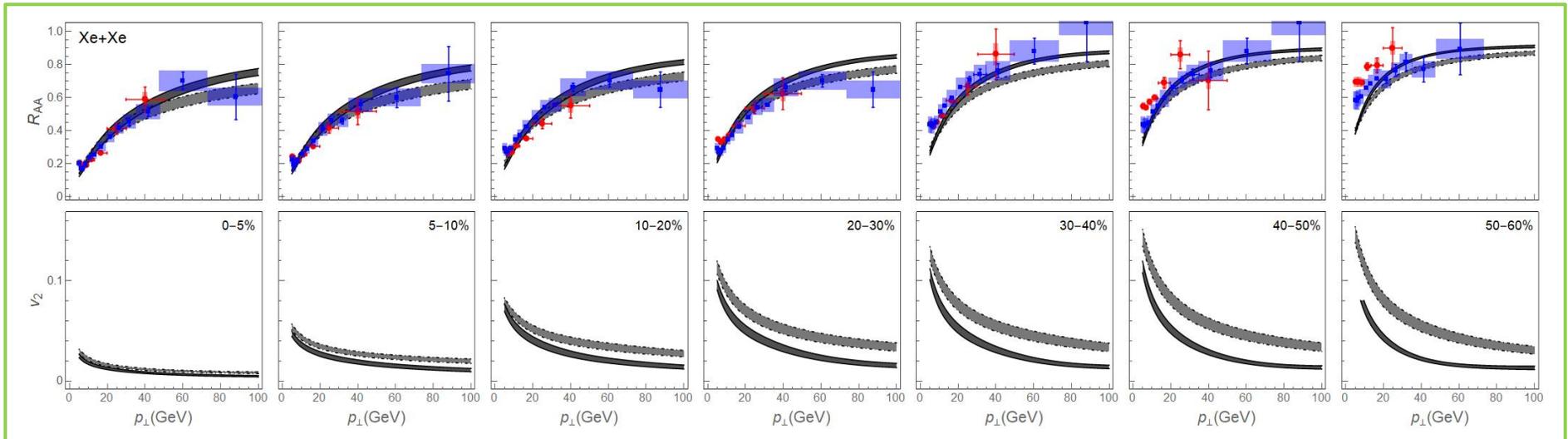


This effect has large influence on v_2 predictions, confirming previous observations that v_2 observable is sensitive to medium evolution.

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



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How to differentiate between different energy loss models?

Path length dependence (energy loss $\sim L^b$) 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 smaller systems (e.g. Xe+Xe) are also becoming available.

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

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 $A^{1/3}$)

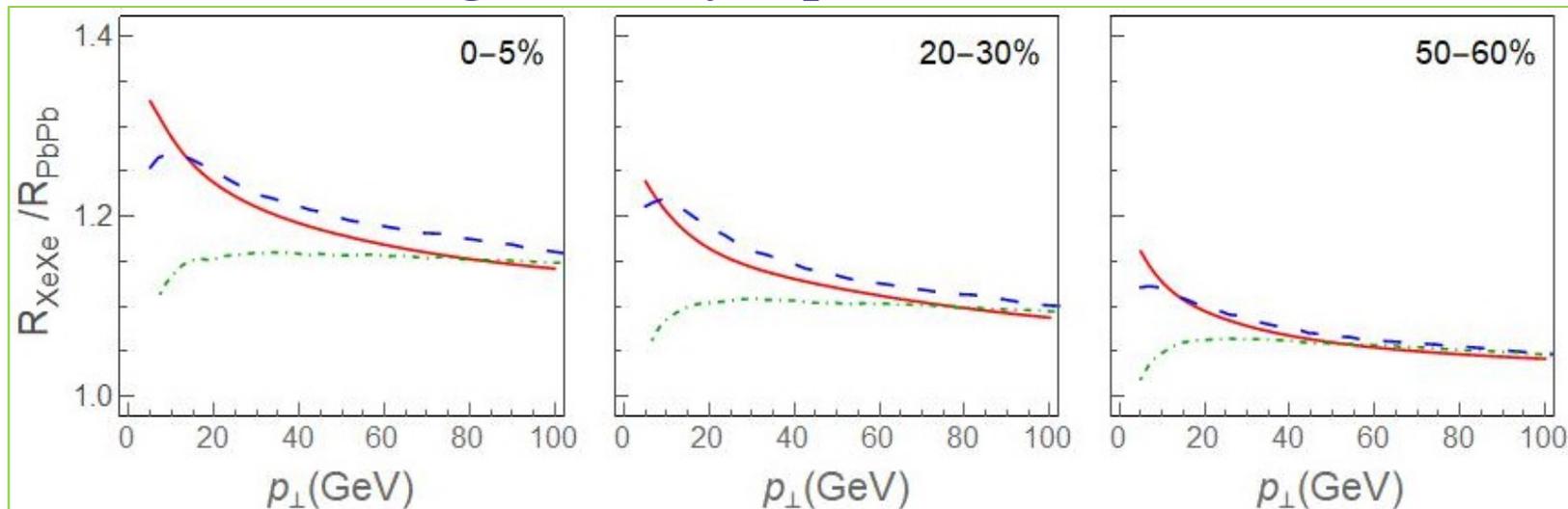
Consequently, comparison of suppressions in Pb+Pb and Xe+Xe is an excellent way to study the path length dependence.

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:

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

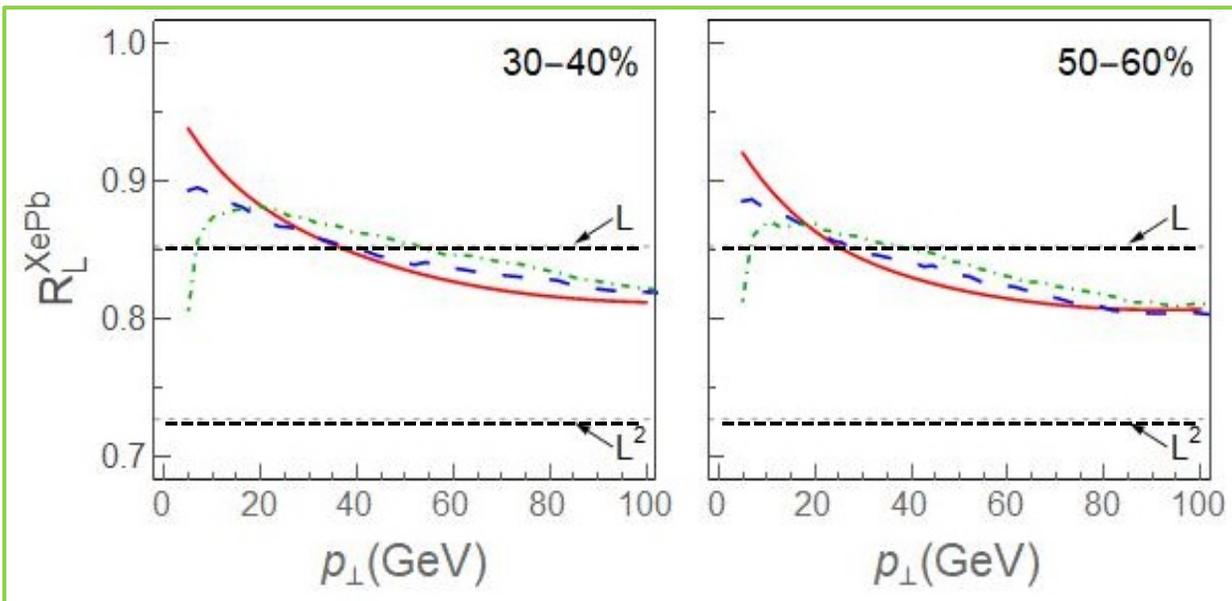
We see that the ratio includes a complicated relationship.

What we propose?

Use $1-R_{AA}$ ratio instead:

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

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



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

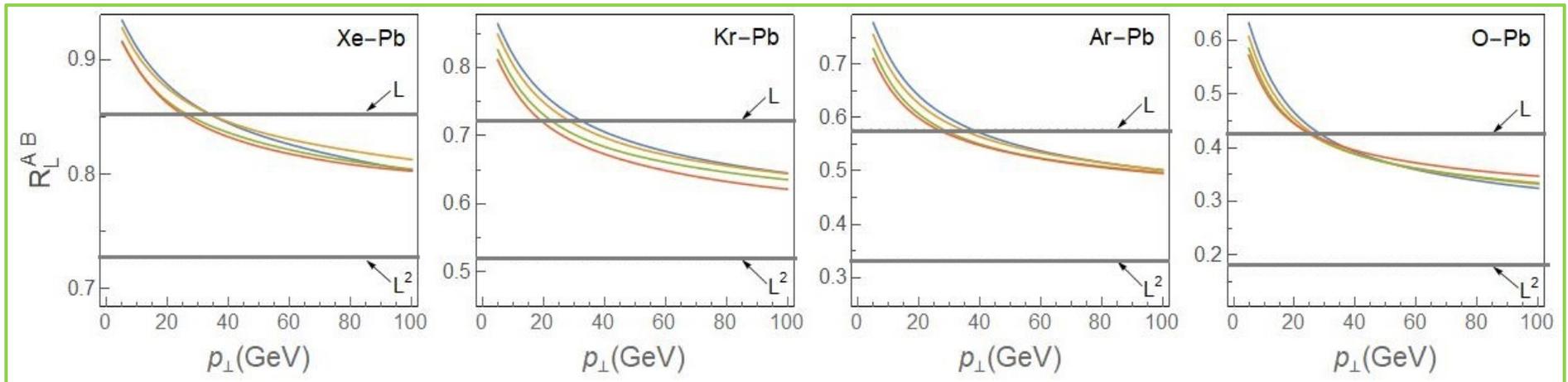
M.D., D. Zigic, M. Djordjevic and J. Auvinen, arXiv:1805.04030

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

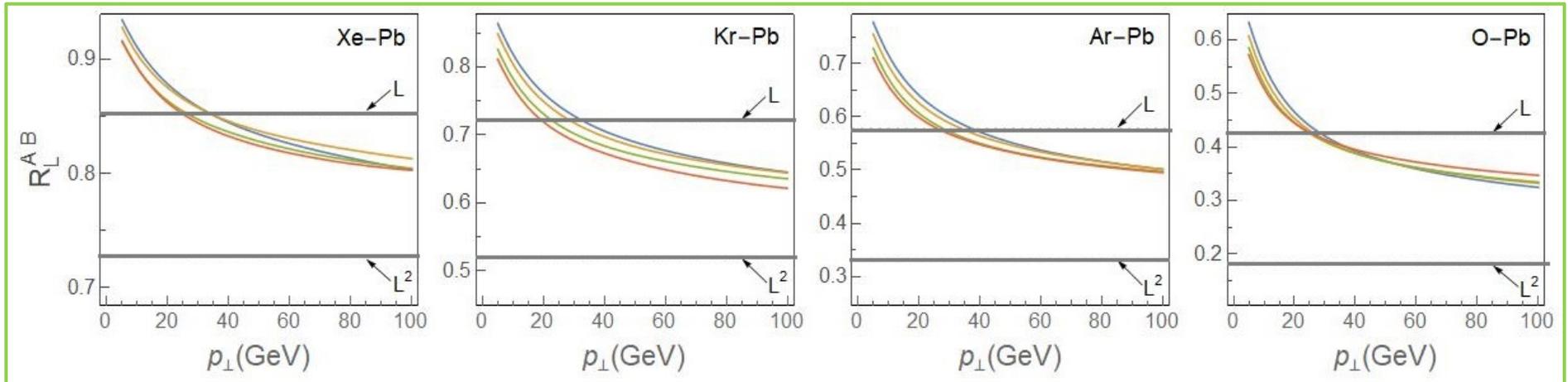
What about other smaller systems?

Measurement of smaller systems, i.e. Kr+Kr, Ar+Ar and O+O, are expected to become available soon.

Can these systems be also used to extract path length dependence of the energy loss?



What about other smaller systems?



- i.* R_L^{AB} is almost independent on centrality for the 20-60% centrality region.
- ii.* For all four systems, R_L^{AB} shows the same behavior, i.e. it is very robust with respect to extracting path-length dependence.
- iii.* From experimental perspective, smaller systems might be more convenient for applying this observable, as the region of applicability (between L and L^2) increases with decreasing system size.

Consequently, we propose that R_L^{AB} is both simple and robust observable for extracting the path-length of the energy loss.¹⁹

Conclusion

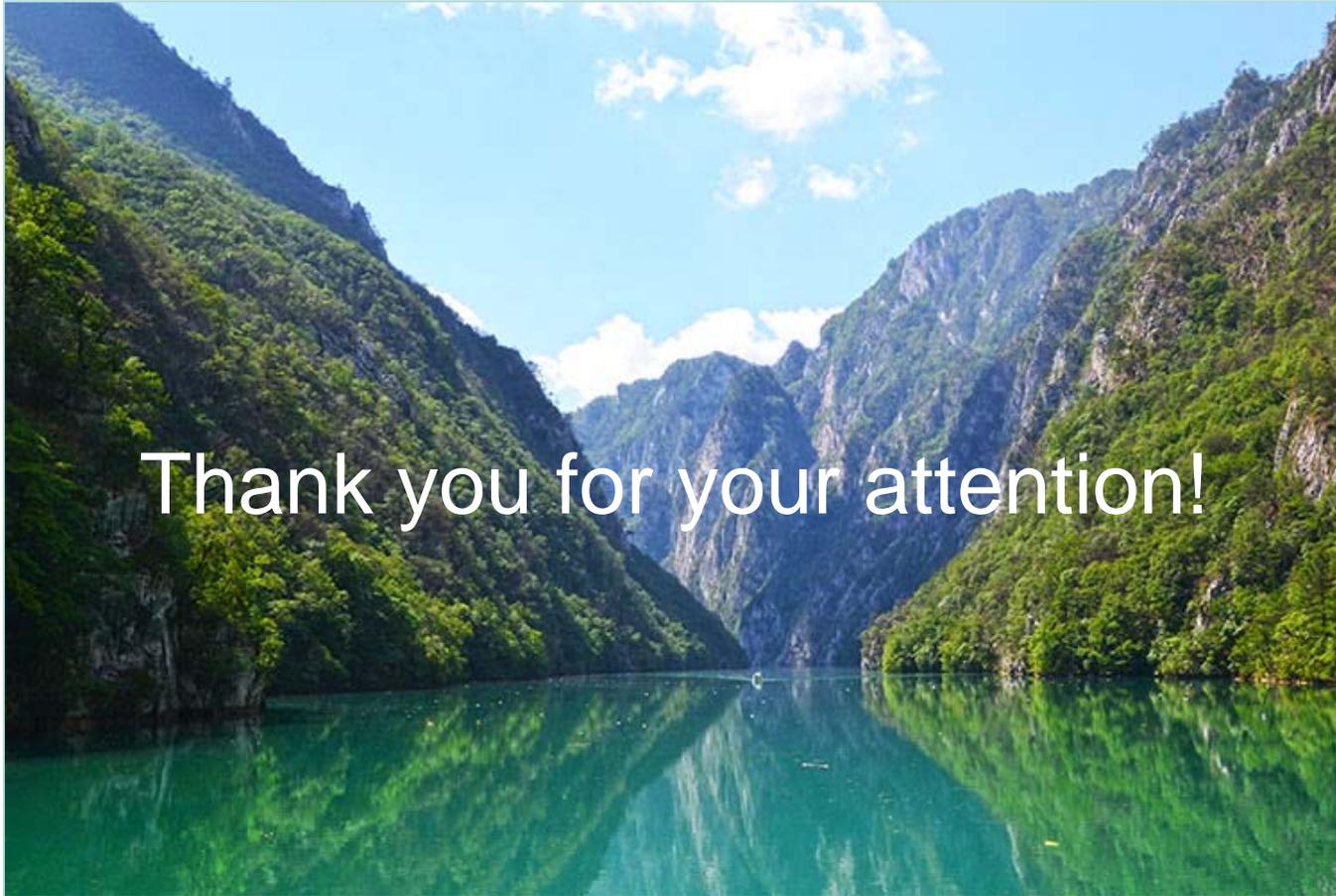
We introduce DREENA-C and DREENA-B frameworks, where DREENA is a computational implementation of the dynamical energy loss formalism.

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, from which energy loss path length dependence can be extracted in a robust and simple manner.

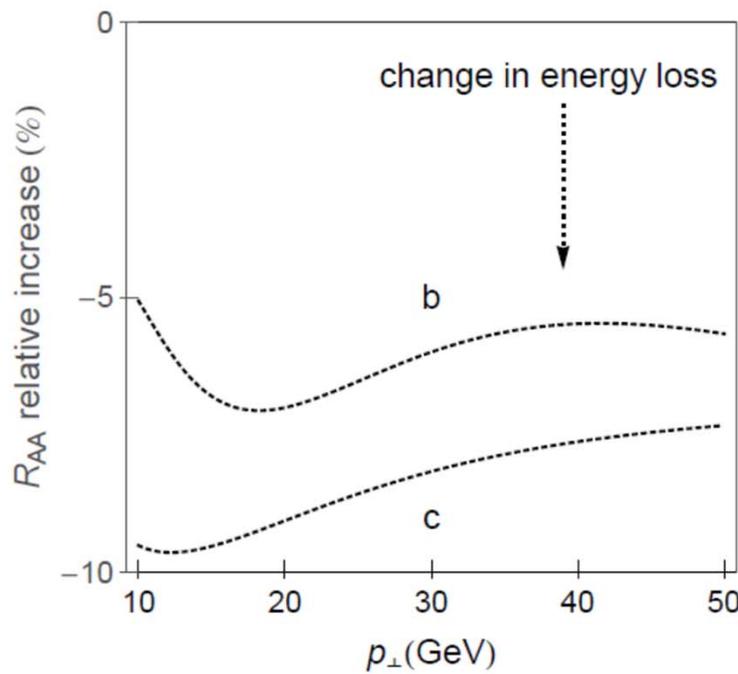
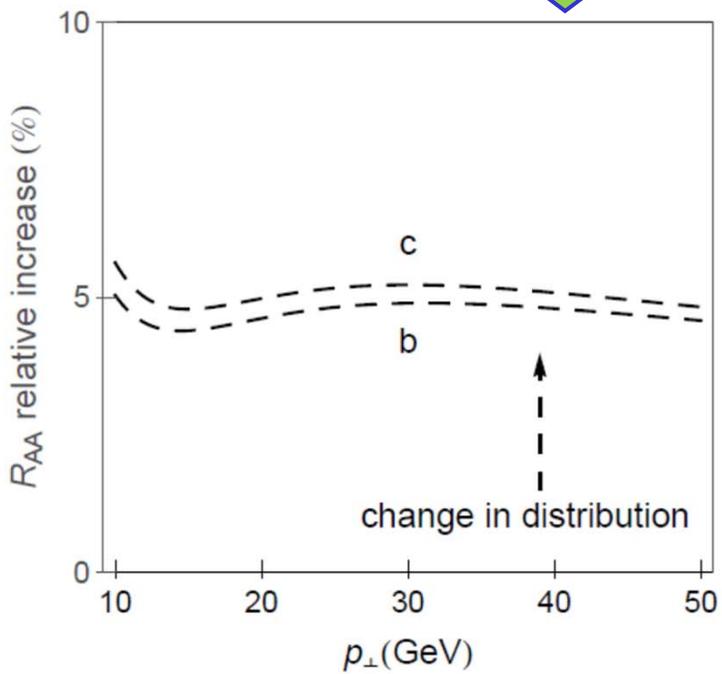
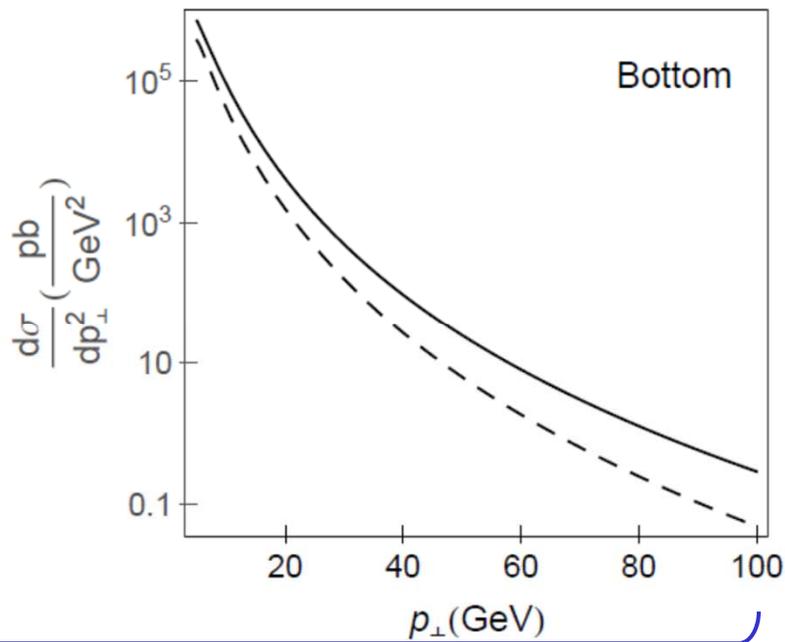
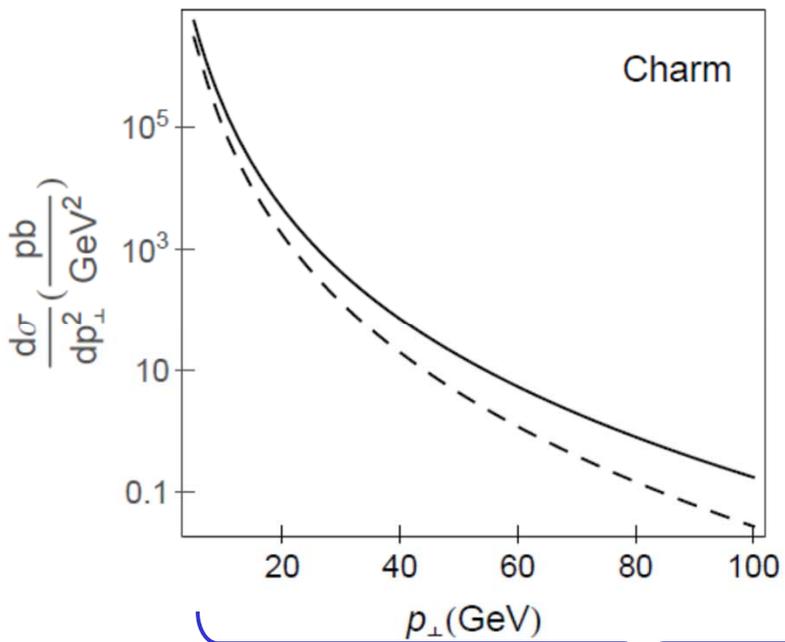
Smaller systems (Kr+Kr, Ar+Ar, O+O) provide an excellent opportunity to assess the path length dependence.

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.



Thank you for your attention!

Canyon of Serbian river DREENA



Temperature dependence of the energy loss

