DREENA framework as a multipurpose tool for QGP tomography

Dusan Zigic

in collaboration with: Magdalena Djordjevic, Jussi Auvinen, Igor Salom, Marko Djordjevic and Pasi Huovinen

МИНИСТАРСТВО ПРОСВЕТЕ,
НАУКЕ И ТЕХНОЛОШКОГ РАЗВОЈА

DREENA framework

- **D**ynamical **R**adiative and **E**lastic **EN**ergy loss **A**pproach

- fully optimized numerical procedure capable of generating high $p_\perp$ predictions
- includes:
  - parton production
  - multi gluon-fluctuations
  - path-length fluctutations
  - fragmentation functions

- keeping all elements of the state-of-the art energy loss formalism, while introducing more complex temperature evolutions

DREENA-C

version **C** - **C**onstant temperature medium

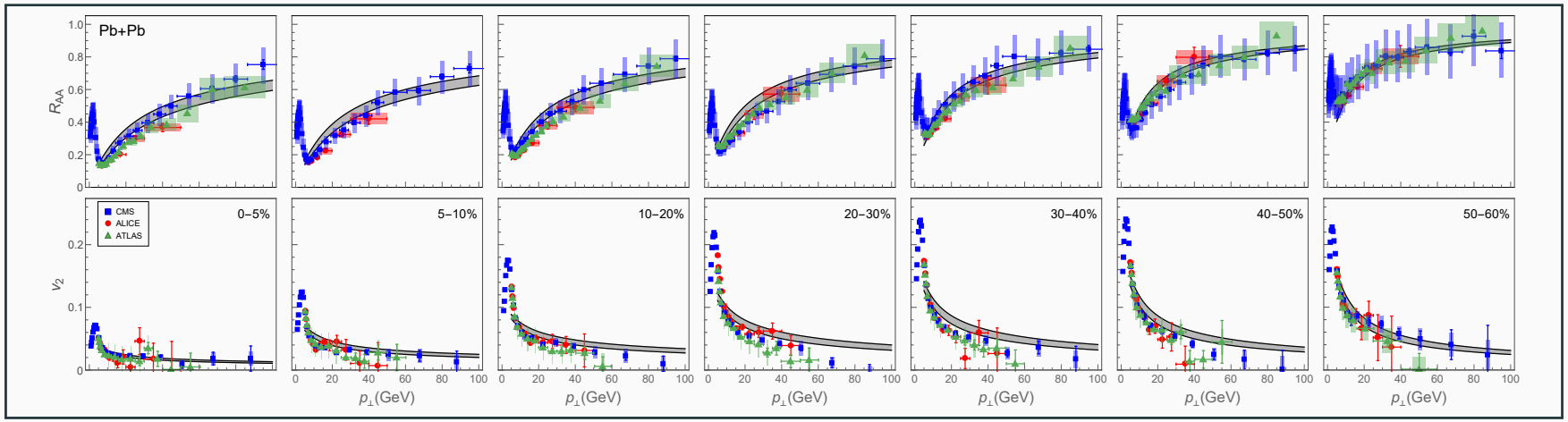
- natural first step
- simplest calculation:
  analytical integration possible in certain cases
- all other version need to have const T limit
- exploring the influence of medium evolution on both light and heavy flavour and different observables

D. Z., I. Salom, J. Auvinen, M. Djordjevic and M. Djordjevic, J. Phys. G **46**, no. 8, 085101 (2019).

DREENA-C

- Charged hadrons, $Pb + Pb$, $\sqrt{s_{NN}} = 5.02\,TeV$

D. Z., I. Salom, J. Auvinen, M. Djordjevic and M. Djordjevic, J. Phys. G **46**, no. 8, 085101 (2019).

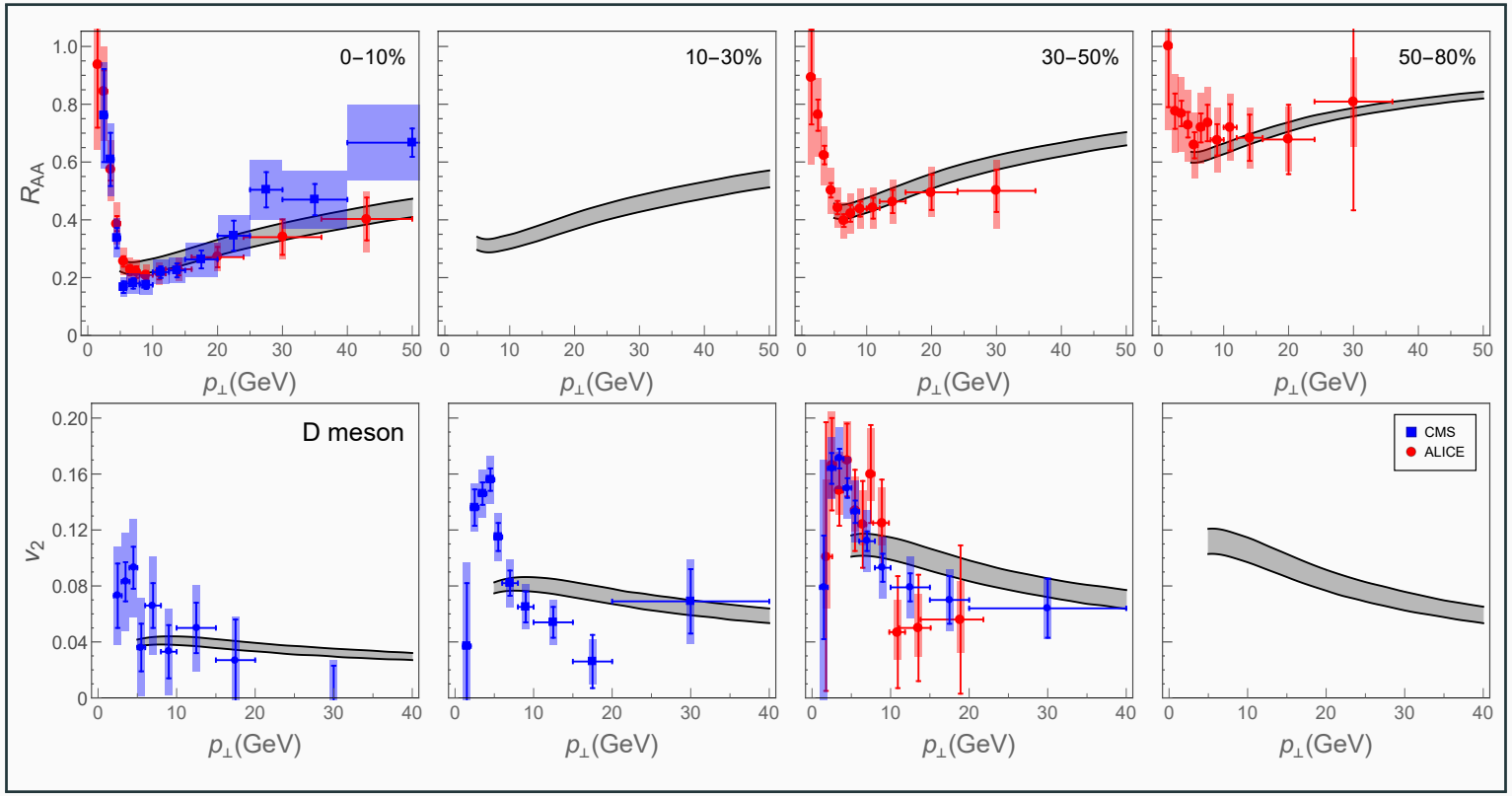


for charged hadrons, qualitatively good agreement,
but overestimation of v_2 data

DREENA-C

- D mesons, $Pb + Pb$, $\sqrt{s_{NN}} = 5.02\,TeV$

D. Z., I. Salom, J. Auvinen, M. Djordjevic and M. Djordjevic, J. Phys. G **46**, no. 8, 085101 (2019).

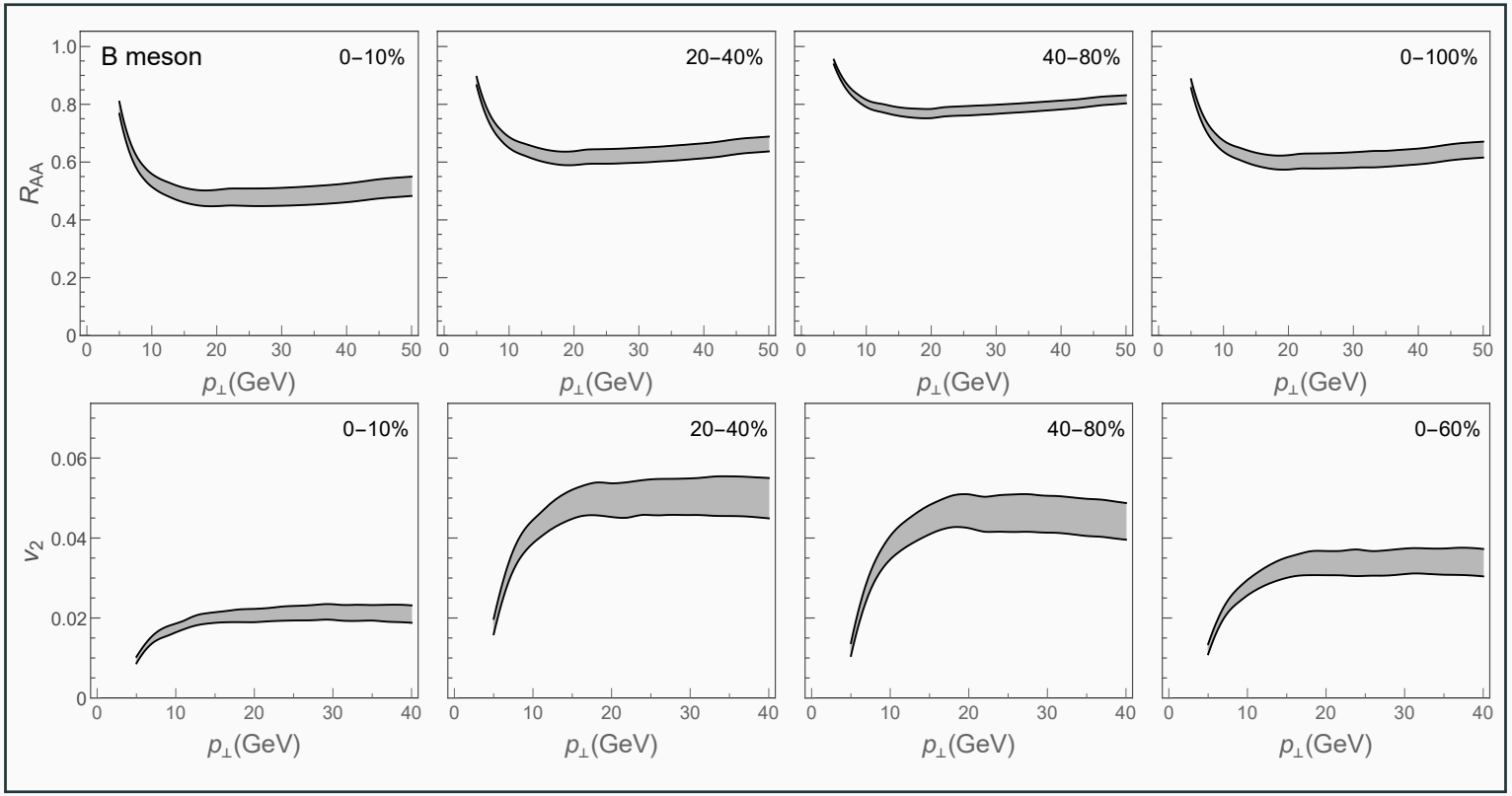


for D mesons, qualitatively good agreement,
but again overestimation of v_2 data

DREENA-C

- B mesons, $Pb + Pb$, $\sqrt{s_{NN}} = 5.02\,TeV$

D. Z., I. Salom, J. Auvinen, M. Djordjevic and M. Djordjevic, J. Phys. G **46**, no. 8, 085101 (2019).



for B mesons, our v_2 predictions are non-zero

DREENA-C

Main conclusions for DREENA-C:

- good agreement with R_{AA} data
- however, v_2 overestimates the data
- other models underestimate v_2 - v_2 puzzle
- overall good agreement with data given the simplicity of approximation

D. Z., I. Salom, J. Auvinen, M. Djordjevic and M. Djordjevic, J. Phys. G **46**, no. 8, 085101 (2019).

DREENA-B

version **B** - 1D **B**jorken evolution

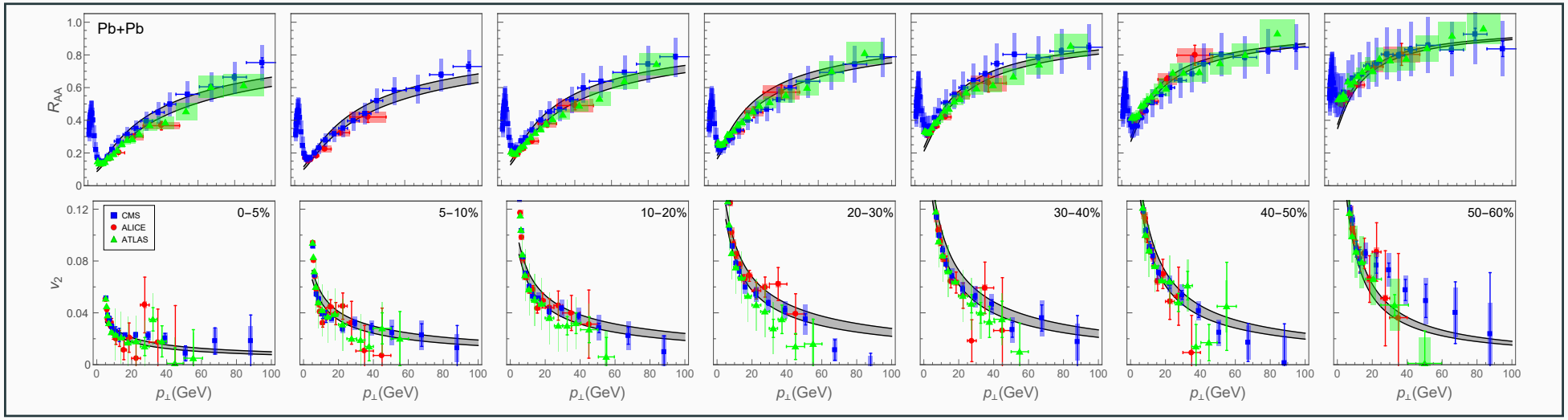
- natural next step
- T introduced through analytical expression, which is only a function of time
- differences in results should suggest the sensitivity of observables to different aspects of medium evolution
- limits prove the validity of models

D. Z., I. Salom, J. Auvinen, M. Djordjevic and M. Djordjevic, Phys. Lett. B **791**, 236 (2019).

DREENA-B

- Charged hadrons, $Pb + Pb, \sqrt{s_{NN}} = 5.02\,TeV$

D Z., I. Salom, J. Auvinen, M. Djordjevic and M. Djordjevic, Phys. Lett. B **791**, 236 (2019).

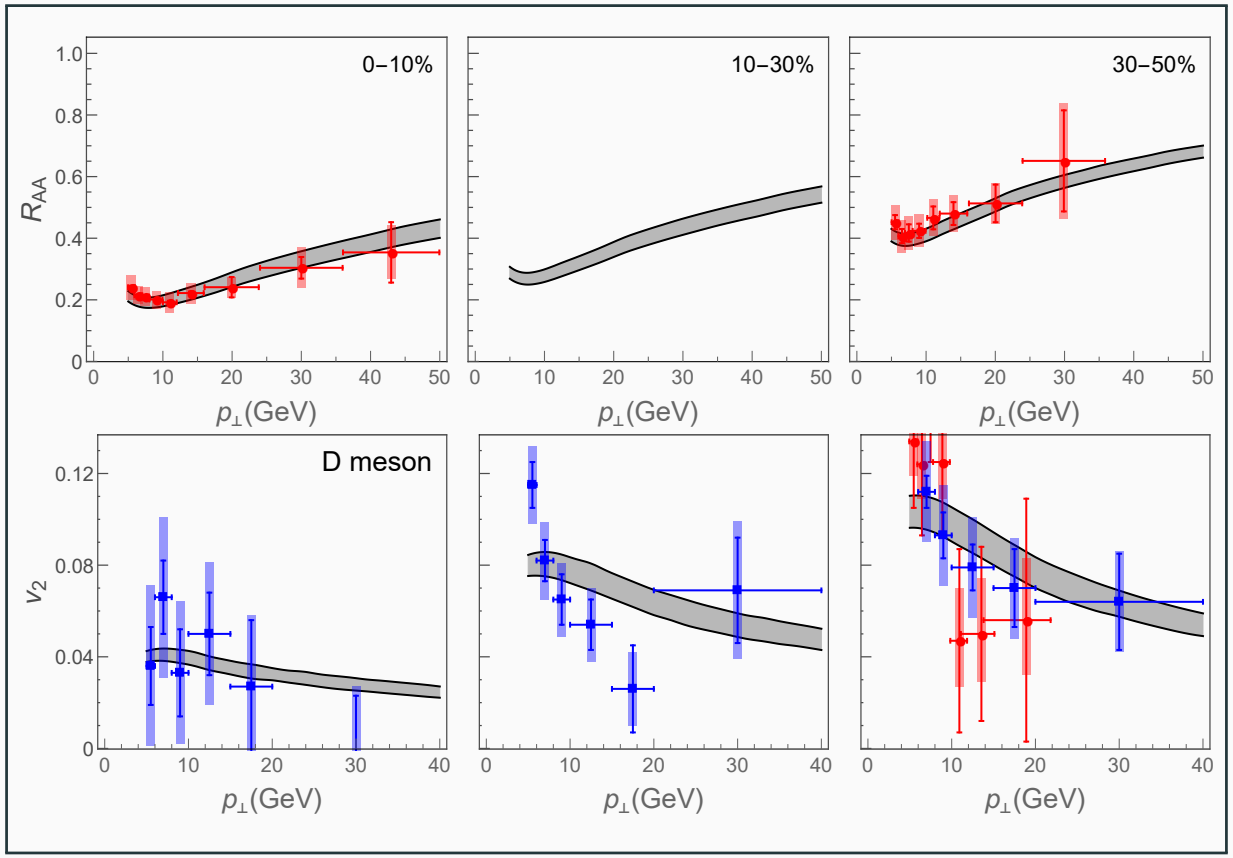


very good joint agreement with both R_{AA} and v_2 data

DREENA-B

- D mesons, $Pb + Pb, \sqrt{s_{NN}} = 5.02\,TeV$

D. Z., I. Salom, J. Auvinen, M. Djordjevic and M. Djordjevic, Phys. Lett. B **791**, 236 (2019).

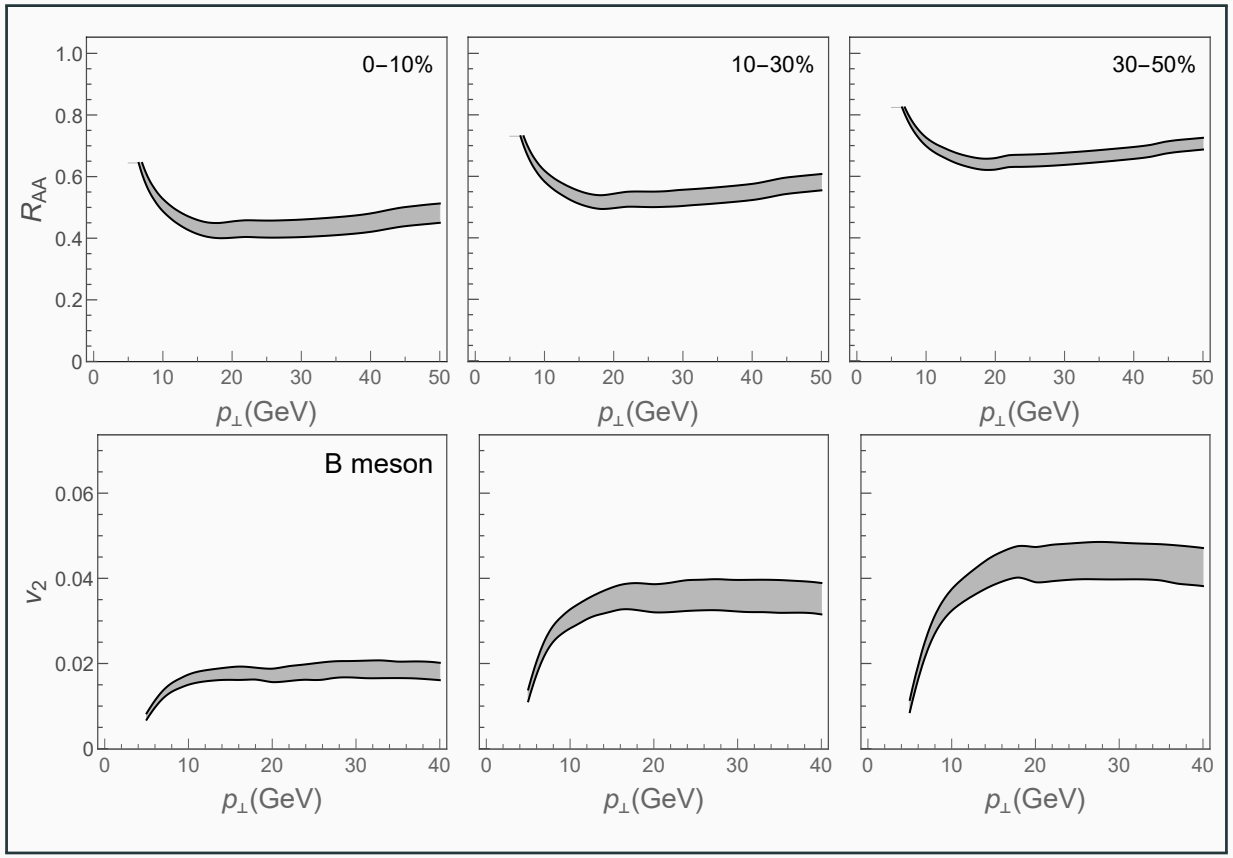


good joint agreement for D mesons as well

DREENA-B

- B mesons, $Pb + Pb, \sqrt{s_{NN}} = 5.02\,TeV$

D. Z., I. Salom, J. Auvinen, M. Djordjevic and M. Djordjevic, Phys. Lett. B **791**, 236 (2019).

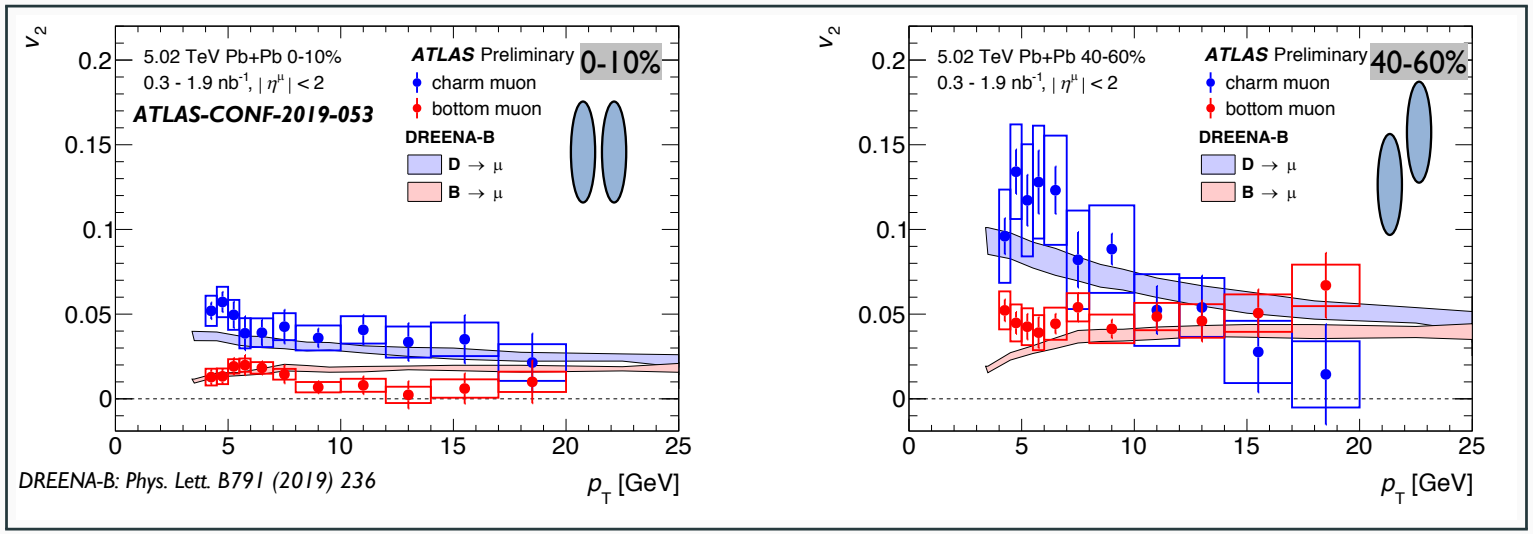


we predict non-zero v_2 for B mesons

DREENA-B

- $Pb + Pb$, $\sqrt{s_{NN}} = 5.02\,TeV$ predictions for muons

D. Z., I. Salom, J. Auvinen, M. Djordjevic and M. Djordjevic, Phys. Lett. B **791**, 236 (2019).



good agreement with the data

DREENA-B

Main conclusions for DREENA-B:

- takes medium evolution as a simple analitycal expression that depends only on time
- explains high $p_\perp$ data for different probes and centralities
- this form of time evolution is suitable for studying the influence of initial stages of QGP evolution on high $p_\perp$ observables
  D. Z., B. Ilic, M. Djordjevic and M. Djordjevic, arXiv:1908.11866 [hep-ph]
- yet, it can't provide us with futher information about the properties of QGP (shear viscosity,...)

D. Z., I. Salom, J. Auvinen, M. Djordjevic and M. Djordjevic, Phys. Lett. B **791**, 236 (2019).

DREENA-A

version **A** - **A**daptive

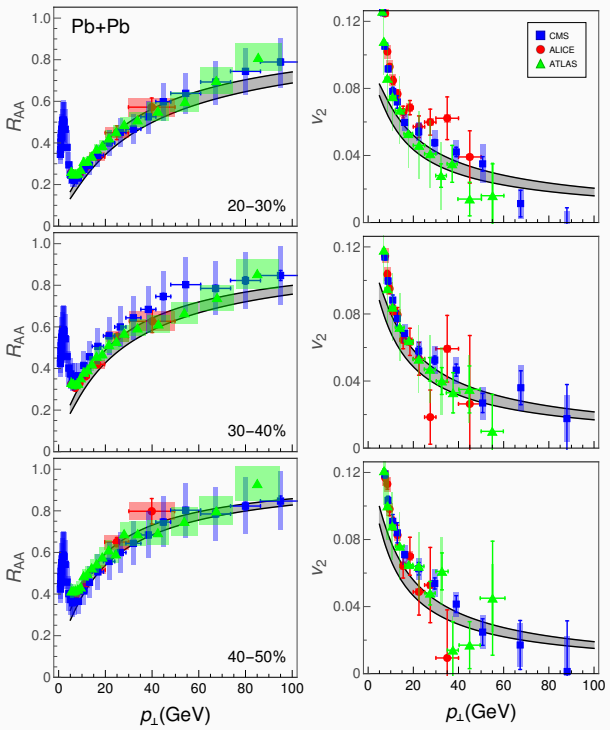
- main goal of our research
- tool for exploiting high $p_\perp$ data for QGP tomography by employing advanced medium model (hydro, transport coefficients,...)
- DREENA-A introduces full medium evolution but not at the expense of simplified energy loss
- also capable to account for event-by-event fluctuations

DREENA-A

- Glb-eBCFit, $\tau_0 = 1.0$ fm

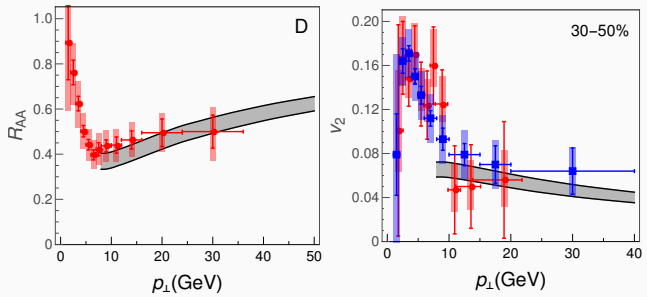
used in **Molnar-Holopainen-Huovinen-Niemi 3d hydro** - energy density based on a third-order polynomial of the BC from optical Glauber

Charged hadrons

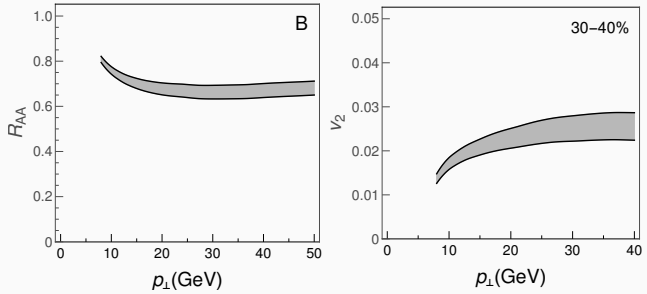


No fitting parameters!

D mesons



B mesons



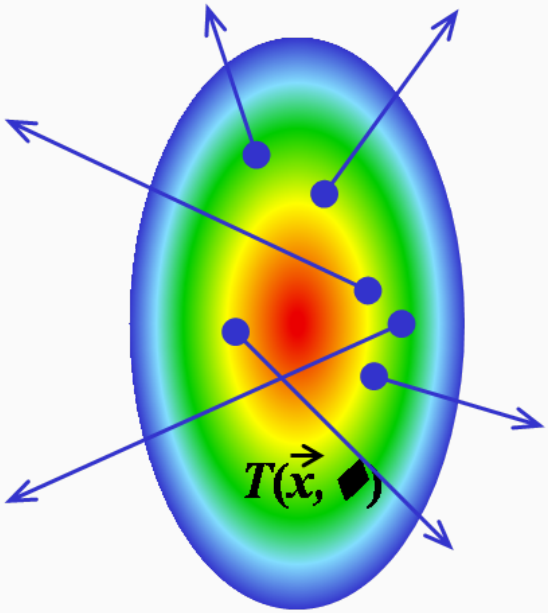
Very good agreement with R_{AA} and v_2 data! ➡ No v_2 puzzle!

⬇

For high-$p_\perp$ data, proper description of parton-medium interactions is more important than the medium evolution!

QGP properties

- Next goal: inferring QGP properties from high $p_\perp$ theory and data



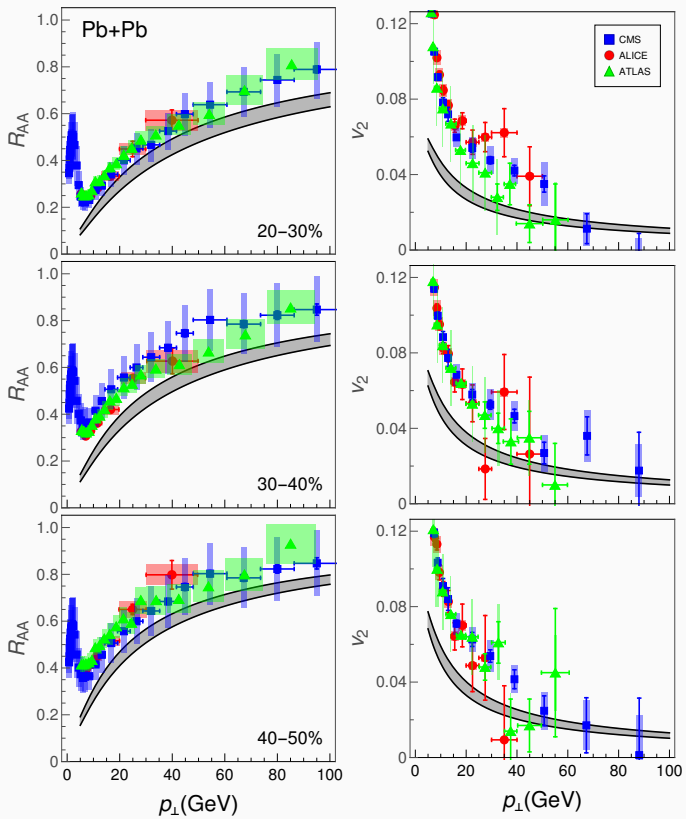
- high energy particles lose energy
- energy loss sensitive to QGP properties
- predict the energy loss of high $p_\perp$ probes
- infer QGP properties:
  - initial spatial anisotropy
    M. Djordjevic, S. Stojku, M. Djordjevic and P. Huovinen, Phys. Rev. C **100**, no. 3, 031901(R) (2019).
  - constrain the initial stages by high $p_\perp$ theory and data
    D. Z., B. Ilic, M.Djordjevic and M. Djordjevic, arXiv:1908.11866 (PRC in press)
  - path-length dependence of energy loss
    M. Djordjevic, D. Z., M. Djordjevic and J. Auvinen, Phys. Rev. C **99**, no. 6, 061902(R) (2019).

Towards QGP tomography - DREENA-A

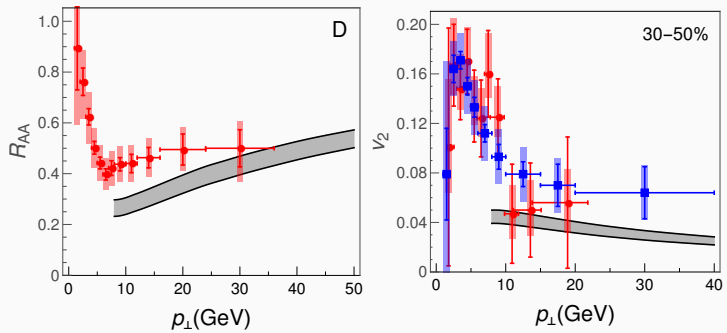
- Glb-eBC, $\tau_0 = 0.5$ fm

used in **SONICv1.7** - energy density based on the BC density from optical Glauber

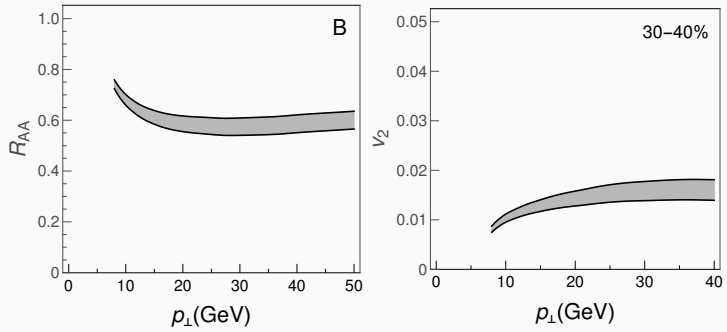
Charged hadrons



D mesons



B mesons

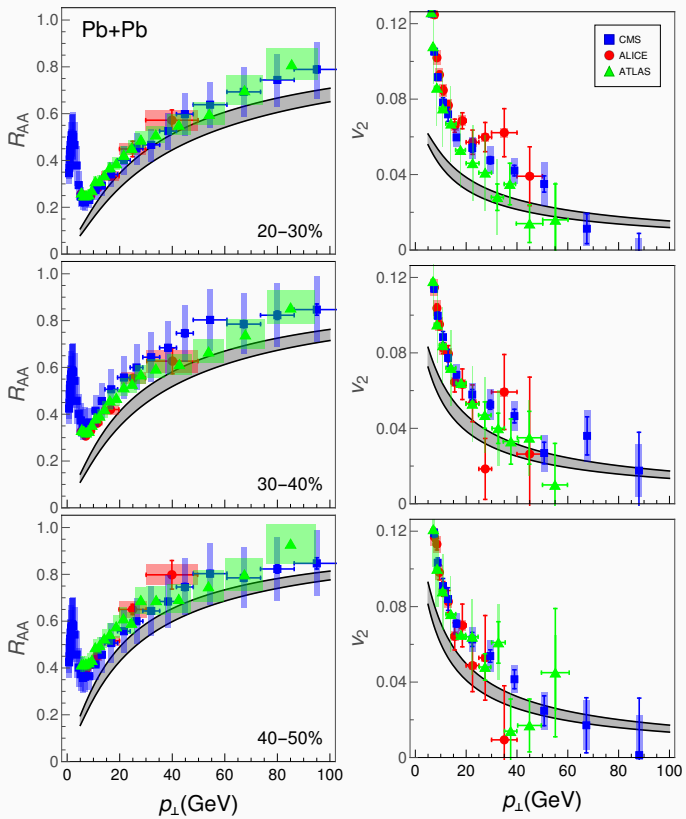


Towards precision QGP tomography - DREENA-A

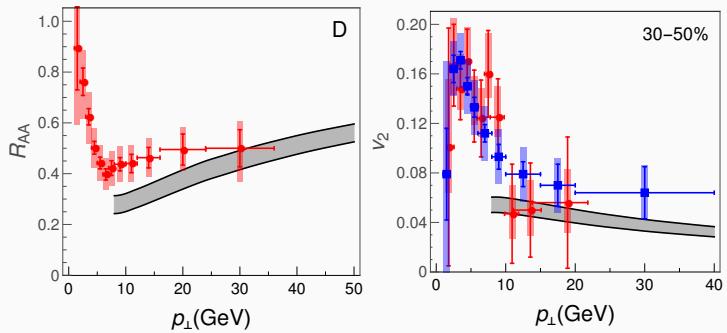
- MCGlb-sMix, $\tau_0 = 0.6$ fm

used in **iEBE-VISHNU** - entropy density based on a mixture of wounded nucleon and BC densities from Monte Carlo Glauber

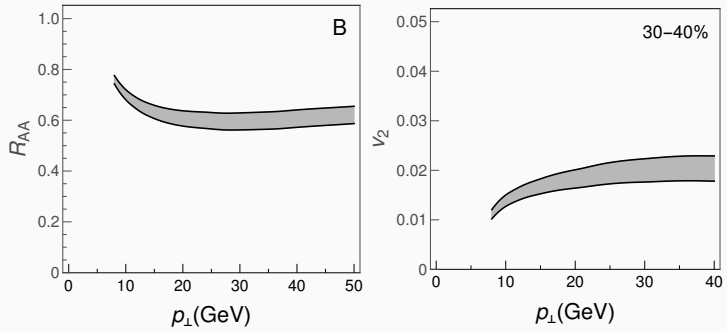
Charged hadrons



D mesons



B mesons



Towards precision QGP tomography - DREENA-A

Analized the sensitivity of high-$p_\perp$ R_{AA} and v_2 data to different hydro temperature profiles.

As a separate study, we also analized sensitivity of high-$p_\perp$ R_{AA} and v_2 data to different initial stages.

D. Z., B. Ilic, M.Djordjevic and M. Djordjevic, arXiv:1908.11866 (PRC in print)

Obtained notable sensitivity shows that high-$p_\perp$ theory/data can indeed be used to constrain the bulk QGP properties.

R_{AA} shows notable sensitivity to initial conditions, while v_2 is surprisingly insensitive to these conditions.

High-$p_\perp$ theory and data are suitable for QGP tomography, but *both* R_{AA} and v_2 have to be tested simultaneously to infer the properties of this new form of matter!

Acknowledgements

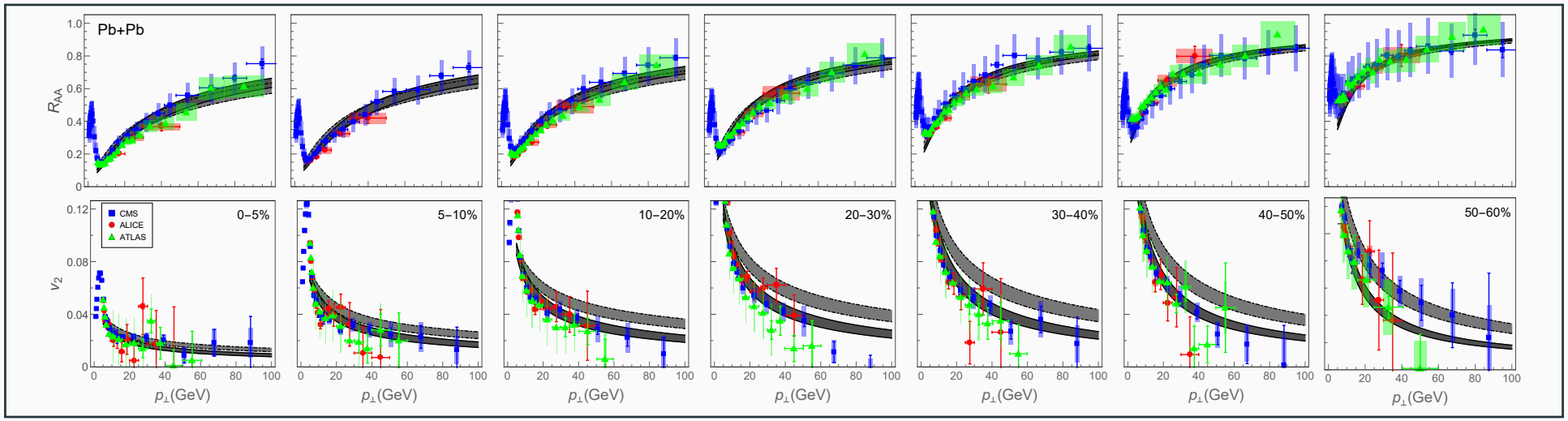
European Research Council
Established by the European Commission

МИНИСТАРСТВО ПРОСВЕТЕ,
НАУКЕ И ТЕХНОЛОШКОГ РАЗВОЈА

Thank you for your attention!

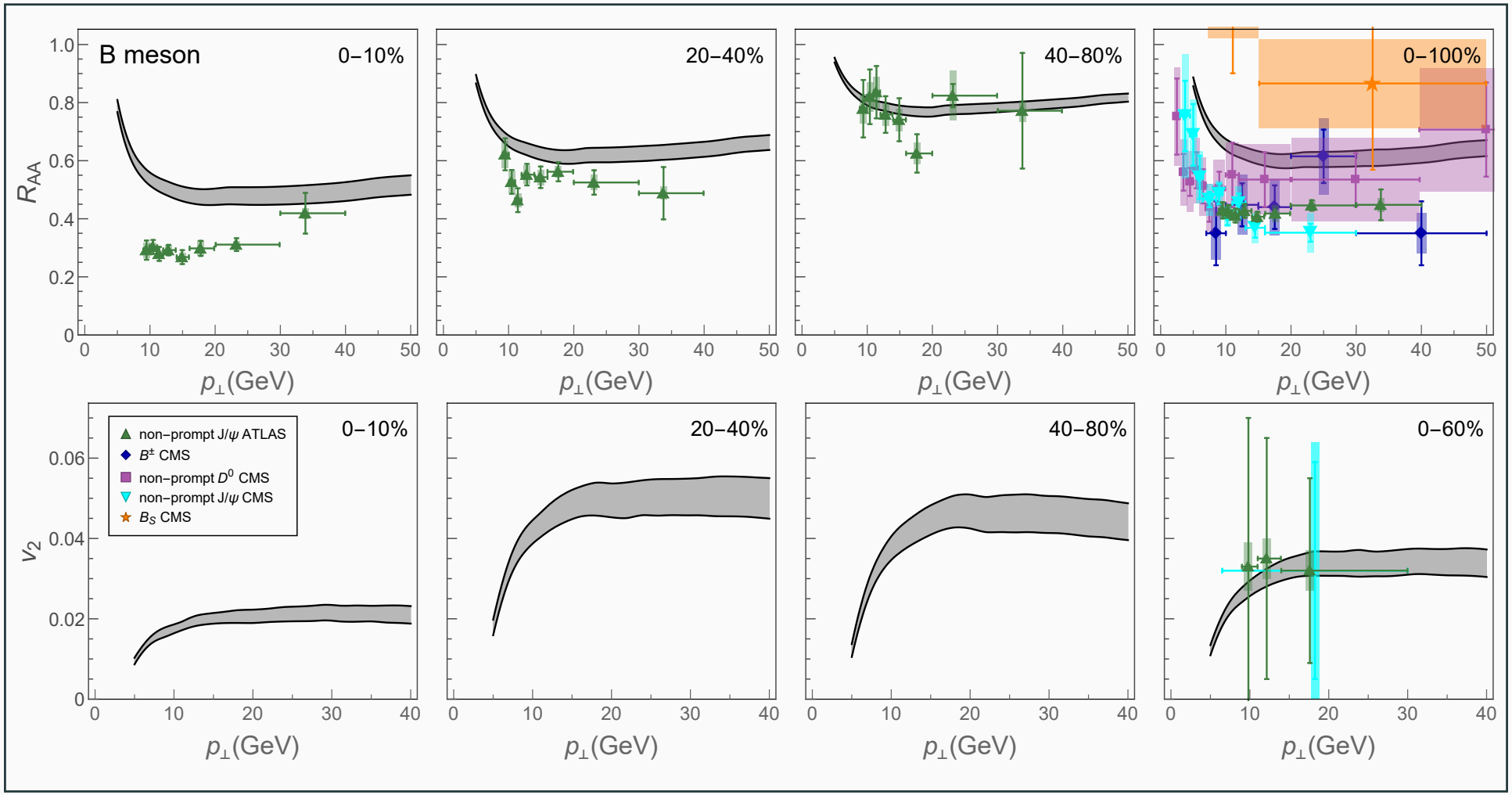
Backup slides

- Charged hadrons, $Pb + Pb, \sqrt{s_{NN}} = 5.02\,TeV$
  DREENA-C & DREENA-B



Backup slides

- B Meson, $Pb + Pb, \sqrt{s_{NN}} = 5.02\,TeV$
  DREENA-C



Backup slides

- Charged hadrons, $Pb + Pb, \sqrt{s_{NN}} = 5.02\,TeV$
  DREENA-C & DREENA-B & DREENA-A