УНИВЕРЗИТЕТ У БЕОГРАДУ
ИНСТИТУТ ЗА ФИЗИКУ | БЕОГРАД
ИНСТИТУТ ОД НАЦИОНАЛНОГ ЗНАЧАЈА ЗА РЕПУБЛИКУ СРБИЈУ

QUARK MATTER KRAKÓW 2022

Extracting the ‘dead cone’ effect through heavy flavor data

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МИНИСТАРСТВО ПРОСВЕТЕ, НАУКЕ И ТЕХНОЛОШКОГ РАЗВОЈА

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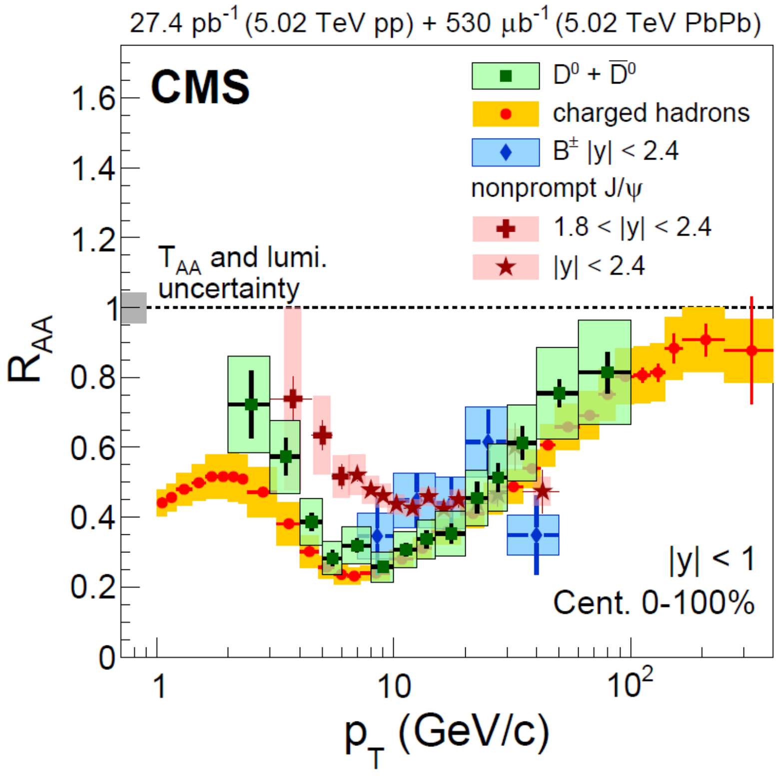
Mass hierarchy effect in energy loss mechanisms

- The experimental observations of R_{AA} mass hierarchy (i.e., dead cone) attributed and analyzed within radiative models PLB 519, 199
- At intermediate-$p_\perp$ range ($p_T \lesssim 10$ GeV) for the charm and bottom quarks the collisional –comparable to, or even larger, than radiative energy loss
- The mass hierarchy in collisional energy loss is not yet addressed
- The upcoming high-precision RHIC and LHC measurements – an opportunity to utilize high-p_T heavy flavor data to analyze the interaction mechanisms in QGP

B. Ilic and M. Djordjevic, arXiv:2203.06646 [hep-ph]



PLB 782, 474-496

- Challenges:
  - A search for an observable, which can disentangle collisional from radiative energy loss
  - Analytical derivation of a direct relation between collisional suppression/energy loss and heavy quark mass
  - Analytical and numerical extraction of the mass hierarchy in collisional energy losses through this observable.

Our approach: DREENA-C framework

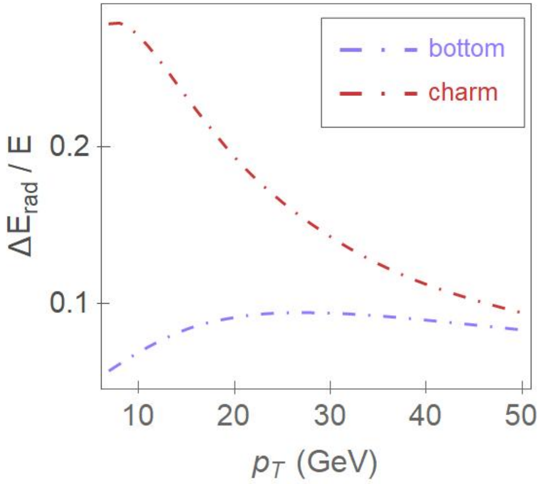
- DREENA-C (Dynamical Radiative and Elastic ENergy loss Approach + Constant temperature):

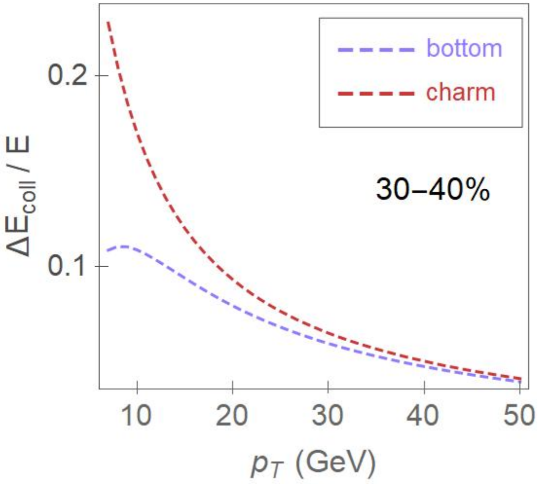
  D. Zigic, I. Salom, J. Auvinen, M. Djordjevic and M. Djordjevic, JPG 46, no.8, 085101

  - It is based on Dynamical energy loss formalism: M. Djordjevic and M. Djordjevic, PLB 734, 286
    - Finite T, finite size medium consisting of dynamical partons
    - Based on finite T Field Theory and generalized HTL approach
    - Collisional + radiative energy losses
    - Finite partons mass, applicable to light and heavy flavor
    - Finite magnetic mass effect
    - Running coupling
    - Relaxed soft-gluon approximation
  - Its predictions are in a very good agreement with experiments, i.e.:
    - High-$p_\perp$ R_{AA} data
    - Both light and heavy flavors (h±, D, B) → explaining heavy-flavor puzzle
    - All available centrality ranges

The framework can adequately describe high-$p_\perp$ parton-medium interactions!

Mass hierarchy in energy loss – search for an observable

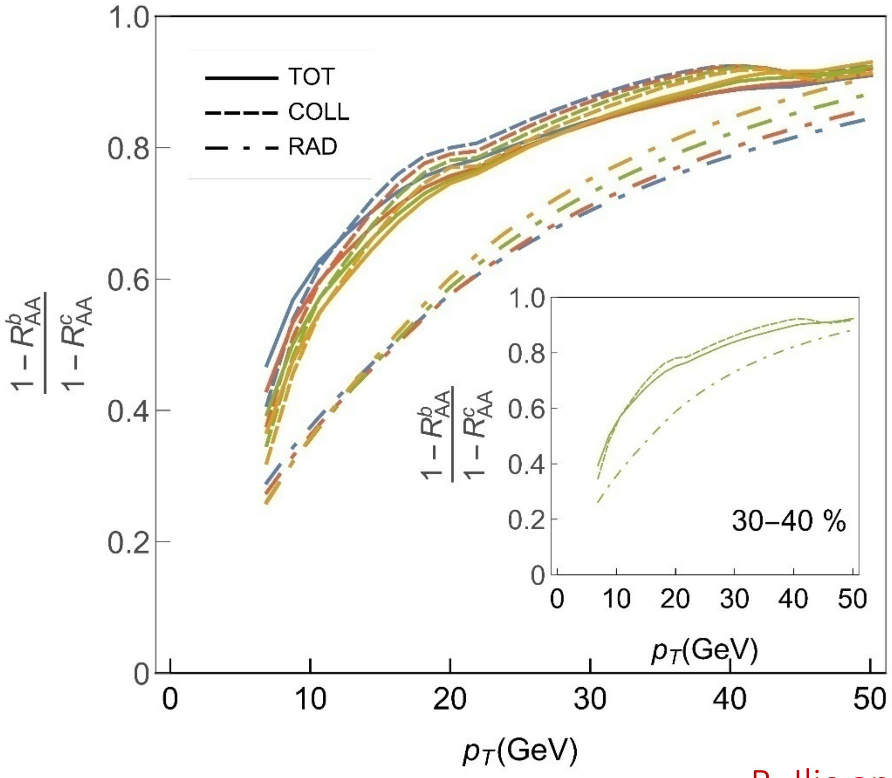




Obtained clear mass hierarchy effect in collisional energy loss!

Which observable could quantify this effect?

Proposition: $f(1 - R_{AA})$, as being particularly sensitive to parton energy loss solely.



Surprisingly: For all centralities TOT and COLL ratios are practically overlapping (and is ~ independent of centrality).

$1 - R_{AA}$ ratio for heavy flavor is dominantly driven by mass hierarchy from collisional energy loss.

B. Ilic and M. Djordjevic, arXiv:2203.06646 [hep-ph]

Analytical derivation: What is reflected through a new observable?

B. Ilic and M. Djordjevic, arXiv:2203.06646 [hep-ph]

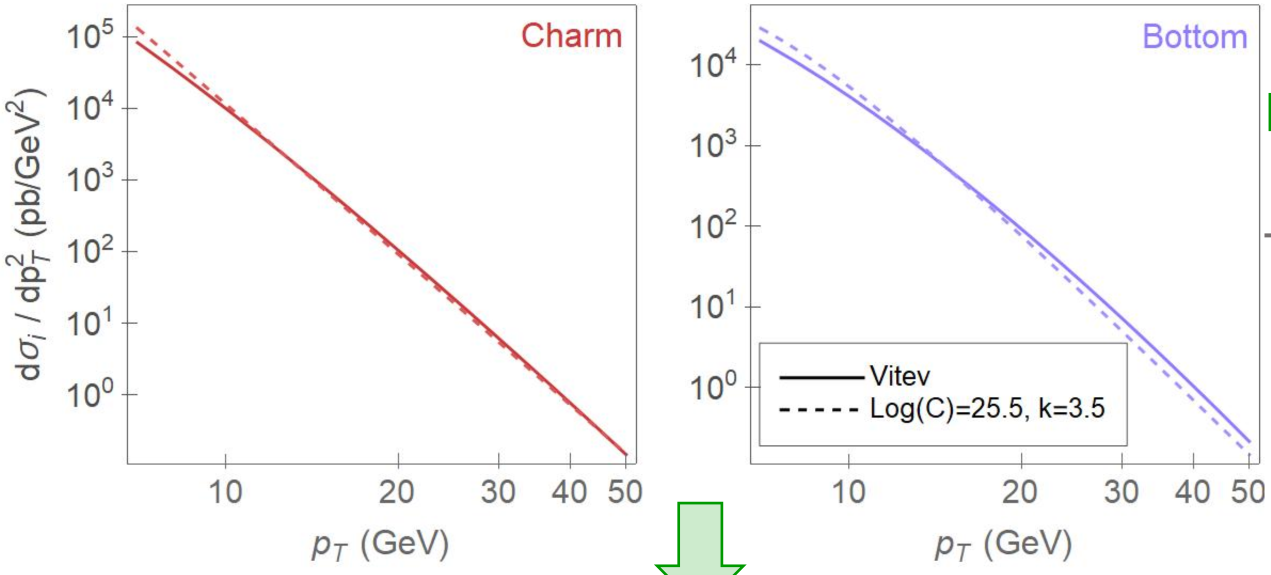
We assume only collisional interactions: $\frac{\Delta E_{coll}}{E} \sim \frac{1}{Ev^2}\left(v + \frac{v^2-1}{2}\ln\left(\frac{1+v}{1-v}\right)\right)$ NPB 351 (3), 491

$$v = \frac{p_T}{\sqrt{p_T^2 + M^2}}$$

Initial distribution parameterization:

$$\frac{d\sigma^i}{dp_T^2} = \frac{C}{(p_T^2 + M^2)^k}$$

PRC 71, 064904



The same C and k for bottom and charm.

Suppression:

$$R_{AA} = \frac{d\sigma^f}{dp_T^2} / \frac{d\sigma^i}{dp_T^2}$$

PRC 71, 064904

$$1 - R_{AA} \simeq 2k \frac{p_T}{E}\frac{\Delta E_{coll}}{E}$$

PLB 718, 482;PRC 80, 054902

Mass dependence relations:

$$\frac{\Delta E_{coll}}{E} \sim \frac{1}{p_T}\left(1 - \frac{M^2}{p_T^2}\ln(2) + \left(\frac{M}{p_T}\right)^{\frac{M}{p_T}+1} - \frac{M}{p_T}\right)$$

$$1 - R_{AA} \sim \frac{2k}{p_T}\left[1 - \frac{M^2}{p_T^2}\left(\ln 2 + \frac{1}{2}\right) + \left(\frac{M}{p_T}\right)^{\frac{M}{p_T}+1} - \frac{M}{p_T}\right]$$

Dominant terms

New observable:

$$\frac{1-R_{AA}^b}{1-R_{AA}^c} \simeq \frac{1-\frac{M_b}{p_T}}{1-\frac{M_c}{p_T}}$$

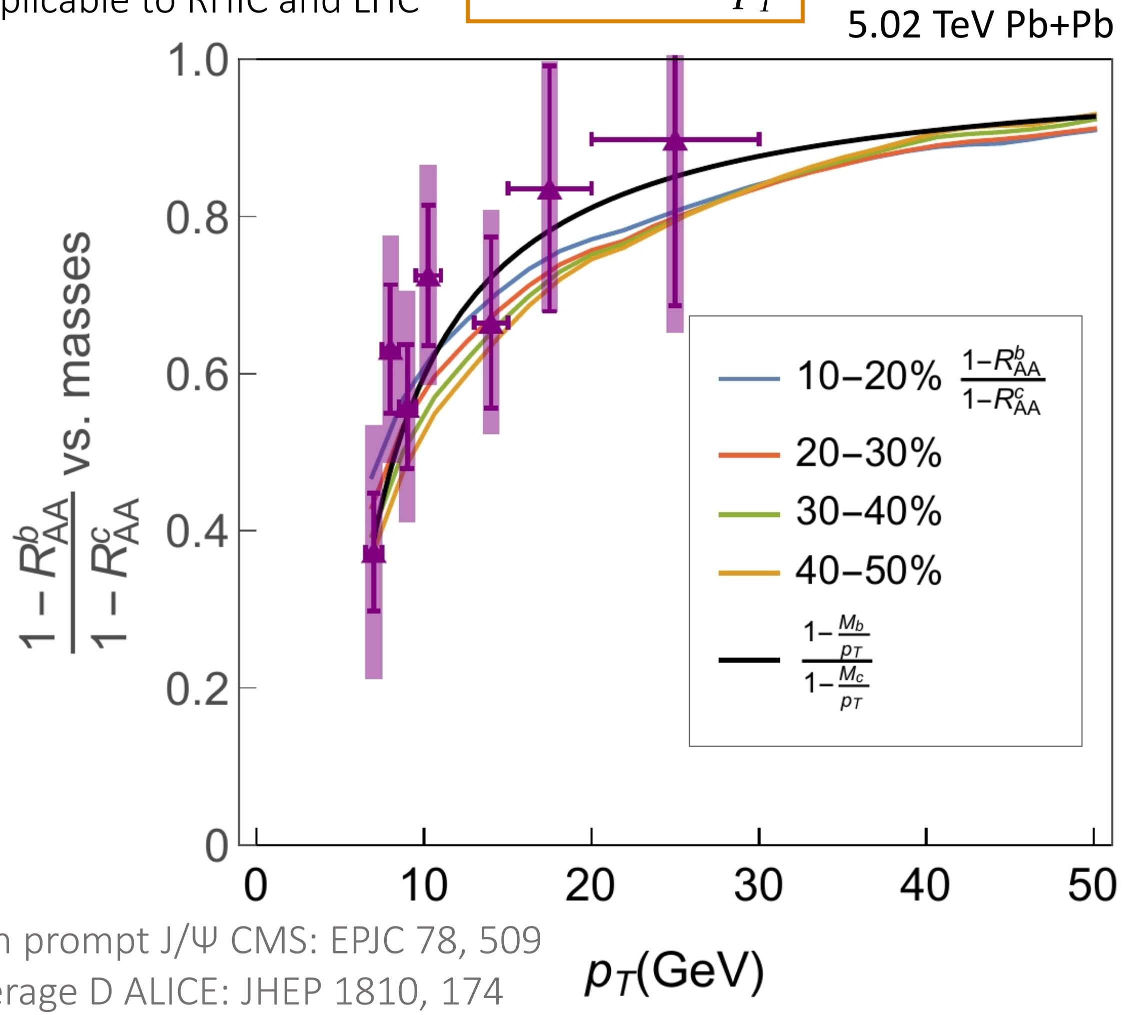
It reflects the mass hierarchy in collisional energy loss!

Testing the adequacy of new observable $\frac{1-R_{AA}^b}{1-R_{AA}^c}$

Surprisingly simple relation:

$$\frac{1-R_{AA}^b}{1-R_{AA}^c} \simeq \frac{1-\frac{M_b}{p_T}}{1-\frac{M_c}{p_T}}$$

Applicable to RHIC and LHC



Non prompt J/Ψ CMS: EPJC 78, 509
Average D ALICE: JHEP 1810, 174

A good agreement between:

DREENA-C predictions and our analytical estimate $\left(1-\frac{M_b}{p_T}\right)/\left(1-\frac{M_c}{p_T}\right)$ (for all centralities). → Implies validity of our analysis.

Data and our predictions (qualitatively and quantitatively) → Supports validity of DREENA-C.

Data and our analytical mass estimate . → Confirms adequacy of proposed observable.

B. Ilic and M. Djordjevic, arXiv:2203.06646 [hep-ph]

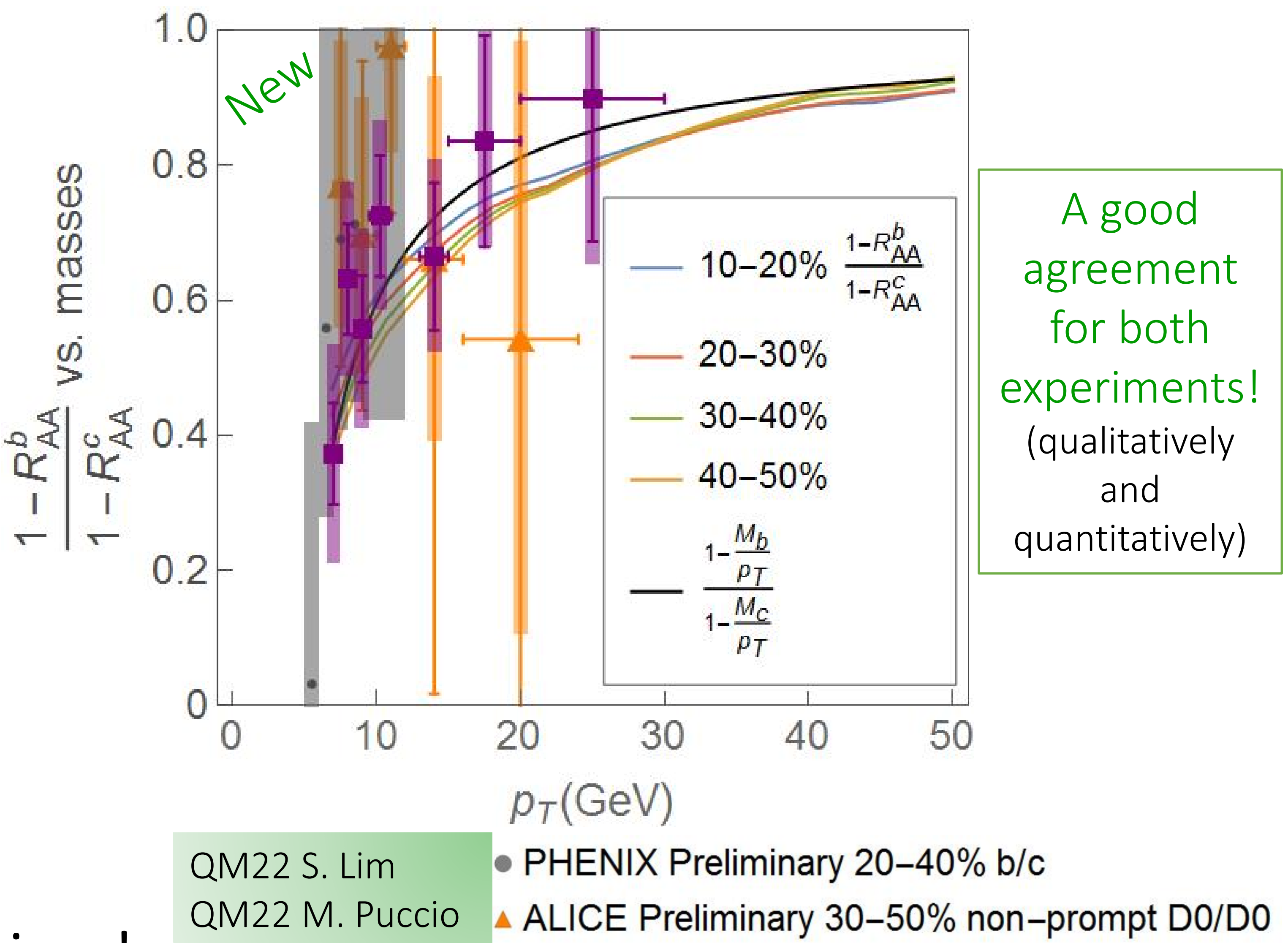
Outlook

- Specific guidelines on where future experimental efforts regarding extracting mass hierarchy in collisional energy loss should be focused:
  - At lower $p_T \rightarrow$ accessible at both RHIC and LHC
  - Higher precision measurements needed
  - B meson suppression data would be beneficial
  - B meson (non-prompt J/Ψ) and D meson suppression data should be provided for the same centrality
  - bins

B. Ilic and M. Djordjevic, arXiv:2203.06646 [hep-ph]

Thank you for your attention!

Test in real time:

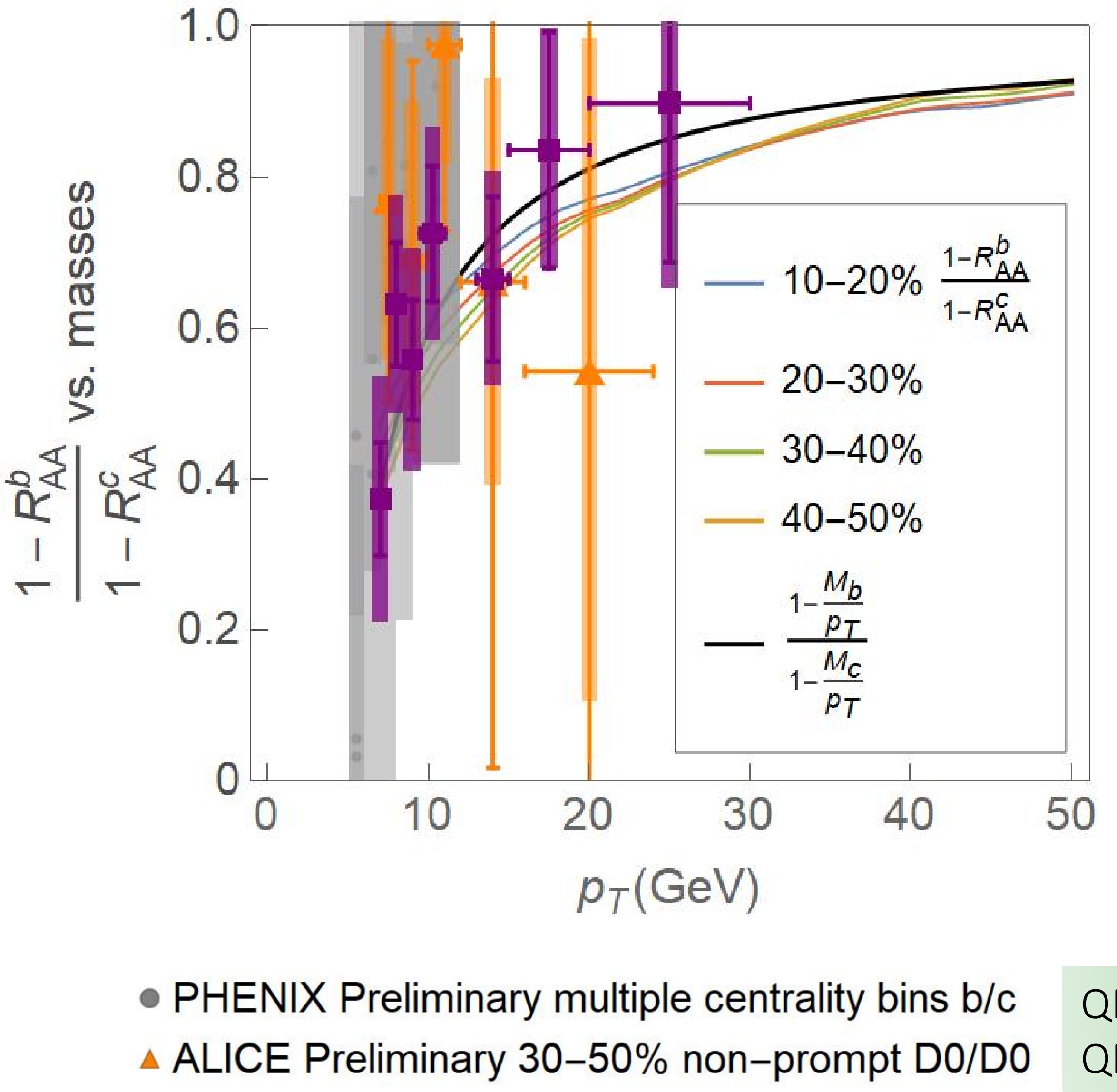


QM22 S. Lim
QM22 M. Puccio

A good agreement for both experiments! (qualitatively and quantitatively)

Backup

New



⇨

A good agreement with preliminary data (qualitatively and quantitatively)

QM22 S. Lim
QM22 M. Puccio

arXiv:2203.17058
arXiv:2202.00815

DREENA-C: Numerical framework

- Heavy flavor production

Z.B. Kang, I. Vitev, H. Xing, PLB 718, 482 (2012); R. Sharma, I. Vitev, and B. W. Zhang, PRC 80, 054902 (2009)

- Dynamical energy loss in a finite size QCD medium

M. Djordjevic and M. Djordjevic, PLB 734, 286 (2014)

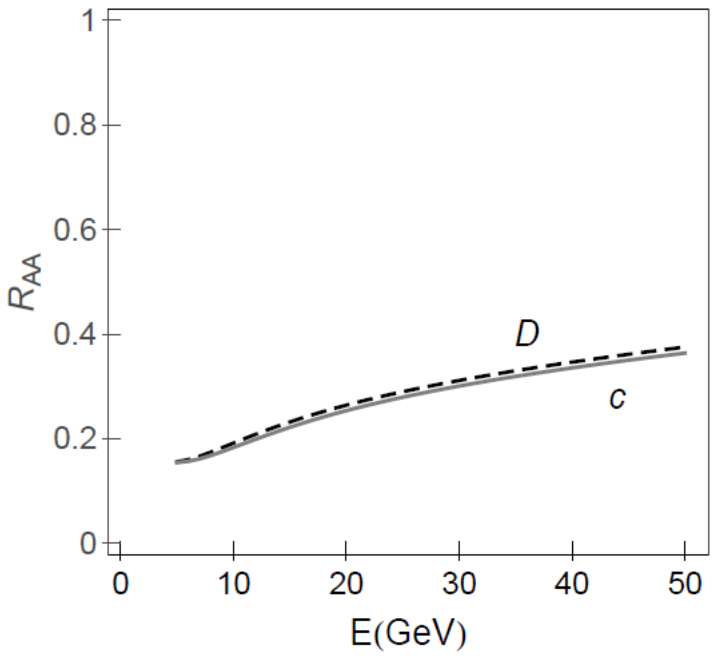
- Multi-gluon fluctuations

M. Gyulassy, P. Levai, I. Vitev, PLB 538, 282 (2002)

- Path-length fluctuations

A. Dainese, EPJ C33, 495 (2004); S. Wicks, W. Horowitz, M. Djordjevic and M. Gyulassy, NPA 784, 426 (2007); D. Zigic, I. Salom, J. Auvinen, M. Djordjevic and M. Djordjevic, JPG 46, 085101 (2019)

It is analytically tractable, and its R_{AA} predictions are practically unaffected by more sophisticated medium evolution models (PRC 85, 044903; NPA 932, 140; JPG 42, 075105; PLB 791, 236; PRC 99, no.6, 061902)



$$\frac{E_f d^3\sigma_f}{dp_f^3} = \frac{E_i d^3\sigma_i(Q)}{dp_i^3} \otimes P(E_i \to E_f)$$

PRL 112, no.4, 042302 (2014)

D and B mesons present genuine charm and bottom probe's suppression.

M. Djordjevic, M. Gyulassy, R. Vogt and S. Wicks, Phys. Lett. B 632, 81-86 (2006)
M. Djordjevic, Phys. Rev. Lett. 112, no.4, 042302 (2014)

Direct and indirect (non-prompt J/Ψ) b observables are barely affected by fragmentation/decay functions in high-$p_\perp$ region.

M. Djordjevic, Phys. Lett. B 763, 439-444 (2016)

$$\frac{d\sigma^f}{dp_T^2}=\int d\varepsilon D(\varepsilon)\frac{d\sigma^i(p_T+\varepsilon)}{dp_T^2}=\int d\varepsilon D(\varepsilon)\frac{d\sigma^i(p_T)}{dp_T^2}+\int d\varepsilon D(\varepsilon)\frac{\varepsilon}{1!}\frac{d}{dp_T}\left(\frac{d\sigma^i(p_T)}{dp_T^2}\right)+\ldots\simeq\frac{d\sigma^i}{dp_T^2}+\Delta E_{coll}\frac{d}{dp_T}\left(\frac{d\sigma^i}{dp_T^2}\right)$$

JHEP 09, 033; PRC 72, 014905

Collisional comparable to (or even larger than) radiative energy loss at higher-$p_\perp$ range:

S. Wicks, W. Horowitz, M. Djordjevic and M. Gyulassy, Nucl. Phys. A 784, 426 (2007)
M. Djordjevic, Phys. Rev. C 74, 064907 (2006)
B. Blagojevic and M. Djordjevic, J. Phys. G 42, 075105 (2015)
M. G. Mustafa, Phys. Rev. C 72, 014905 (2005)
M. G. Mustafa and M. H. Thoma, Acta Phys. Hung. A 22, 93 (2005)