Nuclear Effects In The Inclusive Production of Vectorial Mesons at Proton-Nucleus Collisions

Authors: [1]**Érison dos Santos Rocha** [1]**Magno Valério Trindade Machado**

[1]Institute of Physics of Federal University of Rio Grande do Sul

August/2021

Summary

In this work, we analyze nuclear effects in the inclusive production of vector mesons at p-A collisions;

- Introduction and motivation;
- Theoretical summary;
- Show the results and conclusions;

Summary

In this work, we analyze nuclear effects in the inclusive production of vector mesons at p-A collisions;

- Introduction and motivation;
- Theoretical summary;
- Show the results and conclusions;

Motivation

The understanding of J/ψ production dynamics is a open topic in the high energies nuclear physics.

- In the 80's, the J/ψ suppression was proposed as ultimate test of **quark-gluon plasma (QGP)**[1];
  - $\Rightarrow$ Although useful for study the QGP, it remains as open topic;
- The **cold nuclear effects** is similar to J/ψ suppression and affects his production;
- Therefore, a better understanding of this picture enhance the knowledge of QGP impact in this meson production[2];
- ★ One way of estimate such effects is through **Nuclear Modification Factors (R_{AB})**[3], that is cross section's dependent;

The increasing of hadron production with quantum numbers not present in the colliding matter is one of oldest signal of QGP medium[4, 5].

The quarkonium suppression is a theoretical proposal of a clear signature of deconfined matter.

Motivation

The understanding of J/ψ production dynamics is a open topic in the high energies nuclear physics.

- In the 80's, the J/ψ suppression was proposed as ultimate test of **quark-gluon plasma (QGP)**[1];
  $\Rightarrow$ Although useful for study the QGP, it remains as open topic;
- The **cold nuclear effects** is similar to J/ψ suppression and affects his production;
- Therefore, a better understanding of this picture enhance the knowledge of QGP impact in this meson production[2];
- ★ One way of estimate such effects is through **Nuclear Modification Factors (R_{AB})**[3], that is cross section's dependent;

The increasing of hadron production with quantum numbers not present in the colliding matter is one of oldest signal of QGP medium[4, 5].

The quarkonium suppression is a theoretical proposal of a clear signature of deconfined matter.

Motivation

The understanding of J/ψ production dynamics is a open topic in the high energies nuclear physics.

- In the 80's, the J/ψ suppression was proposed as ultimate test of **quark-gluon plasma (QGP)**[1];
  $\Rightarrow$ Although useful for study the QGP, it remains as open topic;
- The **cold nuclear effects** is similar to J/ψ suppression and affects his production;
- Therefore, a better understanding of this picture enhance the knowledge of QGP impact in this meson production[2];

★ One way of estimate such effects is through **Nuclear Modification Factors (R_{AB})**[3], that is cross section's dependent;

The increasing of hadron production with quantum numbers not present in the colliding matter is one of oldest signal of QGP medium[4, 5].

The quarkonium suppression is a theoretical proposal of a clear signature of deconfined matter.

Motivation

The understanding of J/ψ production dynamics is a open topic in the high energies nuclear physics.

- In the 80's, the J/ψ suppression was proposed as ultimate test of **quark-gluon plasma (QGP)**[1];
  $\Rightarrow$ Although useful for study the QGP, it remains as open topic;
- The **cold nuclear effects** is similar to J/ψ suppression and affects his production;
- Therefore, a better understanding of this picture enhance the knowledge of QGP impact in this meson production[2];
- ★ One way of estimate such effects is through **Nuclear Modification Factors (R_{AB})**[3], that is cross section's dependent;

The increasing of hadron production with quantum numbers not present in the colliding matter is one of oldest signal of QGP medium[4, 5].

The quarkonium suppression is a theoretical proposal of a clear signature of deconfined matter.

Motivation

The understanding of J/ψ production dynamics is a open topic in the high energies nuclear physics.

- In the 80's, the J/ψ suppression was proposed as ultimate test of **quark-gluon plasma (QGP)**[1];
  $\Rightarrow$ Although useful for study the QGP, it remains as open topic;
- The **cold nuclear effects** is similar to J/ψ suppression and affects his production;
- Therefore, a better understanding of this picture enhance the knowledge of QGP impact in this meson production[2];
- ★ One way of estimate such effects is through **Nuclear Modification Factors (R_{AB})**[3], that is cross section's dependent;

The increasing of hadron production with quantum numbers not present in the colliding matter is one of oldest signal of QGP medium[4, 5].

The quarkonium suppression is a theoretical proposal of a clear signature of deconfined matter.

Motivation

The understanding of J/ψ production dynamics is a open topic in the high energies nuclear physics.

- In the 80's, the J/ψ suppression was proposed as ultimate test of **quark-gluon plasma (QGP)**[1];
  $\Rightarrow$ Although useful for study the QGP, it remains as open topic;
- The **cold nuclear effects** is similar to J/ψ suppression and affects his production;
- Therefore, a better understanding of this picture enhance the knowledge of QGP impact in this meson production[2];
- ★ One way of estimate such effects is through **Nuclear Modification Factors (R_{AB})**[3], that is cross section's dependent;

The increasing of hadron production with quantum numbers not present in the colliding matter is one of oldest signal of QGP medium[4, 5].

The quarkonium suppression is a theoretical proposal of a clear signature of deconfined matter.

Quarkonium production cross section

- In this work, we consider the quarkonium production cross section in the **quasi-classical QCD dipole model**[6–8]:
- The quasi-classical approach takes the nuclei as being describe by a classic color field, i.e., that obey Yang-Mills equations;
- Basically, the cross section is obtained form the **contributions that takes place before and after the last inelastic gluon-nuclei interaction**:

Differential cross section for J/ψ production in pA collisions[9]

$$\frac{d\sigma_{pA\to J/\psi X}}{dy\,d^2b} = x_1 G(x_1, m_c^2) \int_0^1 dz \int \frac{d^2r}{4\pi} \Phi(r,z) \int_0^1 dz' \int \frac{d^2r'}{4\pi} \Phi(r',z') \frac{4\vec{r}\cdot\vec{r}'}{(\vec{r}+\vec{r}')^2} \times \left(\left[1 - N_A((\vec{r}-\vec{r}')/2, y)\right] - \left[1 - N_F(\vec{r}, y)\right] \left[1 - N_F(\vec{r}', y)\right] \right); \quad (1)$$

The generalization done in Eq. (1) allow us to use dipole scattering amplitude models;

Quarkonium production cross section

- In this work, we consider the quarkonium production cross section in the **quasi-classical QCD dipole model**[6–8]:
- The quasi-classical approach takes the nuclei as being describe by a classic color field, i.e., that obey Yang-Mills equations;
- Basically, the cross section is obtained form the **contributions that takes place before and after the last inelastic gluon-nuclei interaction**:

Differential cross section for J/ψ production in pA collisions[9]

$$\frac{d\sigma_{pA\to J/\psi X}}{dy\,d^2b} = x_1 G(x_1, m_c^2) \int_0^1 dz \int \frac{d^2r}{4\pi} \Phi(r,z) \int_0^1 dz' \int \frac{d^2r'}{4\pi} \Phi(r',z') \frac{4\vec{r}\cdot\vec{r}'}{(\vec{r}+\vec{r}')^2} \times \Big(\big[1 - N_A((\vec{r}-\vec{r}')/2, y)\big] - [1 - N_F(\vec{r}, y)] \big[1 - N_F(\vec{r}', y)\big] \Big)\,; \quad (1)$$

The generalization done in Eq. (1) allow us to use dipole scattering amplitude models;

Quarkonium production cross section

- In this work, we consider the quarkonium production cross section in the **quasi-classical QCD dipole model**[6–8]:
- The quasi-classical approach takes the nuclei as being describe by a classic color field, i.e., that obey Yang-Mills equations;
- Basically, the cross section is obtained form the **contributions that takes place before and after the last inelastic gluon-nuclei interaction**:

Differential cross section for J/ψ production in pA collisions[9]

$$\frac{d\sigma_{pA\to J/\psi X}}{dy\,d^2b} = x_1 G(x_1, m_c^2) \int_0^1 dz \int \frac{d^2r}{4\pi} \Phi(r,z) \int_0^1 dz' \int \frac{d^2r'}{4\pi} \Phi(r',z') \frac{4\vec{r}\cdot\vec{r}'}{(\vec{r}+\vec{r}')^2} \times \left(\left[1 - N_A((\vec{r}-\vec{r}')/2, y)\right] - \left[1 - N_F(\vec{r}, y)\right] \left[1 - N_F(\vec{r}', y)\right] \right); \quad (1)$$

The generalization done in Eq. (1) allow us to use dipole scattering amplitude models;

Quarkonium production cross section

- In this work, we consider the quarkonium production cross section in the **quasi-classical QCD dipole model**[6–8]:
- The quasi-classical approach takes the nuclei as being describe by a classic color field, i.e., that obey Yang-Mills equations;
- Basically, the cross section is obtained form the **contributions that takes place before and after the last inelastic gluon-nuclei interaction**:

Differential cross section for J/ψ production in pA collisions[9]

$$\frac{d\sigma_{pA\to J/\psi X}}{dy\,d^2b} = x_1 G(x_1, m_c^2) \int_0^1 dz \int \frac{d^2r}{4\pi} \Phi(r,z) \int_0^1 dz' \int \frac{d^2r'}{4\pi} \Phi(r',z') \frac{4\vec{r}\cdot\vec{r}'}{(\vec{r}+\vec{r}')^2} \times \Big(\Big[1 - N_A((\vec{r}-\vec{r}')/2, y)\Big] - \big[1 - N_F(\vec{r}, y)\big] \Big[1 - N_F(\vec{r}', y)\Big] \Big)\,; \quad (1)$$

The generalization done in Eq. (1) allow us to use dipole scattering amplitude models;

Dipole scattering amplitude models

In this work, we make use of the following models:

The Golec-Biernat-Wustoff (GBW) phenomenological amplitude model

The GBW amplitude model [10, 11] propose a parametrization of the dipole cross section from the **Deep Inelastic Scattering** data, due the difficulties of modelling the non-integrated gluon function;

The Dumitru-Hayashigaki-Jalilian (DHJ) model

The DHJ model [12] suggests improvements in the profile parametrization of dipole regarding the **Kharzeev-Kovchegov-Tuchin (KKT)** model[13, 14], in order to provide a better data description in central rapidity. Such agreement keeps the **Color Glass Condensate** formalism predictions;

The bCGC model

The bCGC model [15] gives the density properties of gluons in the hadrons, both in the longitudinal and transversal dimensions, including the dependency of impact parameter in the saturation scale;

Dipole scattering amplitude models

In this work, we make use of the following models:

The Golec-Biernat-Wustoff (GBW) phenomenological amplitude model

The GBW amplitude model [10, 11] propose a parametrization of the dipole cross section from the **Deep Inelastic Scattering** data, due the difficulties of modelling the non-integrated gluon function;

The Dumitru-Hayashigaki-Jalilian (DHJ) model

The DHJ model [12] suggests improvements in the profile parametrization of dipole regarding the **Kharzeev-Kovchegov-Tuchin (KKT)** model[13, 14], in order to provide a better data description in central rapidity. Such agreement keeps the **Color Glass Condensate** formalism predictions;

The bCGC model

The bCGC model [15] gives the density properties of gluons in the hadrons, both in the longitudinal and transversal dimensions, including the dependency of impact parameter in the saturation scale;

Dipole scattering amplitude models

In this work, we make use of the following models:

The Golec-Biernat-Wustoff (GBW) phenomenological amplitude model

The GBW amplitude model [10, 11] propose a parametrization of the dipole cross section from the **Deep Inelastic Scattering** data, due the difficulties of modelling the non-integrated gluon function;

The Dumitru-Hayashigaki-Jalilian (DHJ) model

The DHJ model [12] suggests improvements in the profile parametrization of dipole regarding the **Kharzeev-Kovchegov-Tuchin (KKT)** model[13, 14], in order to provide a better data description in central rapidity. Such agreement keeps the **Color Glass Condensate** formalism predictions;

The bCGC model

The bCGC model [15] gives the density properties of gluons in the hadrons, both in the longitudinal and transversal dimensions, including the dependency of impact parameter in the saturation scale;

Dipole scattering amplitude models

In this work, we make use of the following models:

The Golec-Biernat-Wustoff (GBW) phenomenological amplitude model

The GBW amplitude model [10, 11] propose a parametrization of the dipole cross section from the **Deep Inelastic Scattering** data, due the difficulties of modelling the non-integrated gluon function;

The Dumitru-Hayashigaki-Jalilian (DHJ) model

The DHJ model [12] suggests improvements in the profile parametrization of dipole regarding the **Kharzeev-Kovchegov-Tuchin (KKT)** model[13, 14], in order to provide a better data description in central rapidity. Such agreement keeps the **Color Glass Condensate** formalism predictions;

The bCGC model

The bCGC model [15] gives the density properties of gluons in the hadrons, both in the longitudinal and transversal dimensions, including the dependency of impact parameter in the saturation scale;

Nuclear modification factors R_{pA}

- The main goal of the present work is to evaluate **nuclear modifications factors** R_{pA} in the rapidity spectrum;

$$R_{pA}(y) = \frac{d\sigma_{pA}(y)/dy}{Ad\sigma_{pp}/dy};$$

★ This allow us to analyze the quarkonium suppression as long as $R_{pA}(y)$ differs from the unit;

⇒ In the following, are shown the numerical result from our analyzes for RHIC and LHC;
⇒ We compare it with experimental data from several collaborations
  ★ LHCb [16–19], ALICE [20, 21, 21], CMS [22], ATLAS [23];
  ★ PHENIX [24];

Nuclear modification factors R_{pA}

- The main goal of the present work is to evaluate **nuclear modifications factors** R_{pA} in the rapidity spectrum;

$$R_{pA}(y) = \frac{d\sigma_{pA}(y)/dy}{Ad\sigma_{pp}/dy};$$

★ This allow us to analyze the quarkonium suppression as long as $R_{pA}(y)$ differs from the unit;

⇒ In the following, are shown the numerical result from our analyzes for RHIC and LHC;
⇒ We compare it with experimental data from several collaborations
  ★ LHCb [16–19], ALICE [20, 21, 21], CMS [22], ATLAS [23];
  ★ PHENIX [24];

Nuclear modification factors R_{pA}

- The main goal of the present work is to evaluate **nuclear modifications factors** R_{pA} in the rapidity spectrum;

$$R_{pA}(y) = \frac{d\sigma_{pA}(y)/dy}{Ad\sigma_{pp}/dy};$$

★ This allow us to analyze the quarkonium suppression as long as $R_{pA}(y)$ differs from the unit;

⇒ In the following, are shown the numerical result from our analyzes for RHIC and LHC;
⇒ We compare it with experimental data from several collaborations
  ★ LHCb [16–19], ALICE [20, 21, 21], CMS [22], ATLAS [23];
  ★ PHENIX [24];

Nuclear modification factors R_{pA}

- The main goal of the present work is to evaluate **nuclear modifications factors** R_{pA} in the rapidity spectrum;

$$R_{pA}(y) = \frac{d\sigma_{pA}(y)/dy}{Ad\sigma_{pp}/dy};$$

★ This allow us to analyze the quarkonium suppression as long as $R_{pA}(y)$ differs from the unit;

⇒ In the following, are shown the numerical result from our analyzes for RHIC and LHC;
⇒ We compare it with experimental data from several collaborations
  ★ LHCb [16–19], ALICE [20, 21, 21], CMS [22], ATLAS [23];
  ★ PHENIX [24];

J/ψ results with LHC energies

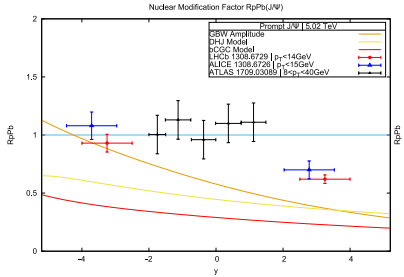

Figure: (a)

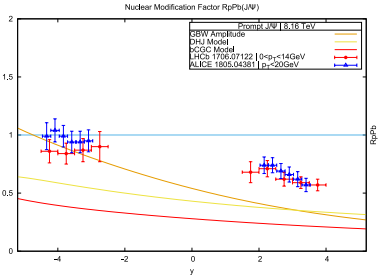

Figure: (b)

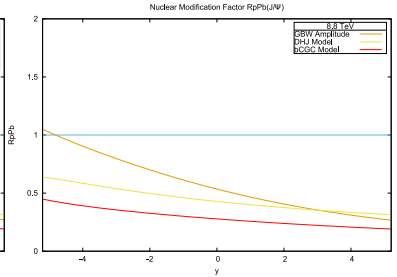

Figure: (c)

- Nuclear modification ratios as function of energy for (a) 5.02 TeV, (b) 8.16 TeV and (c) 8.8 TeV, with LHC data at pPb collision for J/ψ production;
- The results shows suppression higher than the experimental data: (a) $\sim 25\%$ and (b) $\sim 20\%$ at $y \sim 0$; the prediction at (c) shows strong suppression across the entire spectrum ($\sim 75\%$ at forward rapidity);

J/ψ results with LHC energies

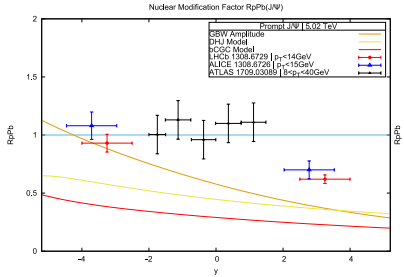

Figure: (a)

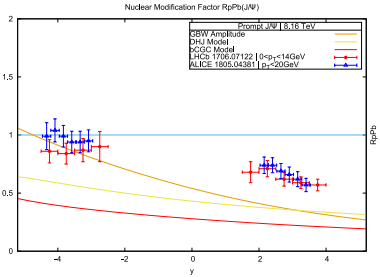

Figure: (b)

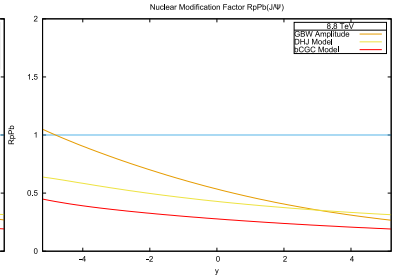

Figure: (c)

- Nuclear modification ratios as function of energy for (a) 5.02 TeV, (b) 8.16 TeV and (c) 8.8 TeV, with LHC data at pPb collision for J/ψ production;
- The results shows suppression higher than the experimental data: (a) $\sim 25\%$ and (b) $\sim 20\%$ at $y \sim 0$; the prediction at (c) shows strong suppression across the entire spectrum ($\sim 75\%$ at forward rapidity);

J/ψ results with RHIC energies

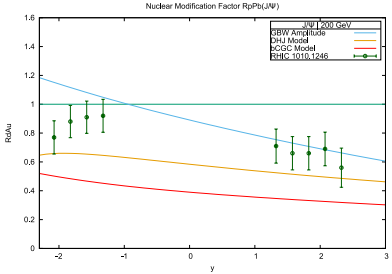

Figure: (a)

- Nuclear modification ratios as function of energy for (a) 200 GeV, with RHIC data at dAu collision for J/ψ production;
- Good agreement with experimental data, but strong suppression for bCGC model;
- $R_{\mathrm{dAu}} > 1$ only for GBW amplitude;

J/ψ results with RHIC energies

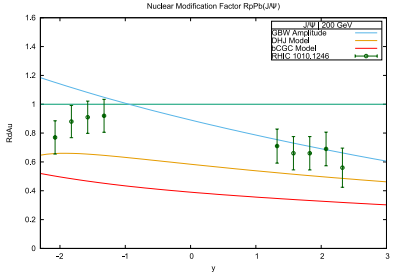

Figure: (a)

- Nuclear modification ratios as function of energy for (a) 200 GeV, with RHIC data at dAu collision for J/ψ production;
- Good agreement with experimental data, but strong suppression for bCGC model;
- $R_{\mathrm{dAu}} > 1$ only for GBW amplitude;

J/ψ results with RHIC energies

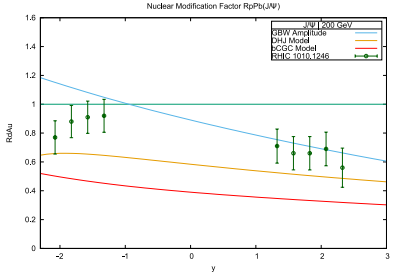

Figure: (a)

- Nuclear modification ratios as function of energy for (a) 200 GeV, with RHIC data at dAu collision for J/ψ production;
- Good agreement with experimental data, but strong suppression for bCGC model;
- $R_{\text{dAu}} > 1$ only for GBW amplitude;

Υ results with LHC energies

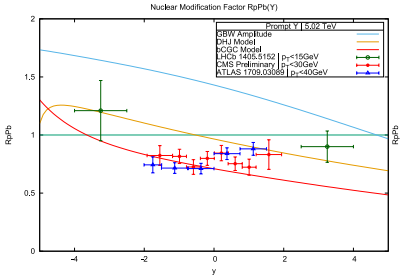

Figure: (a)

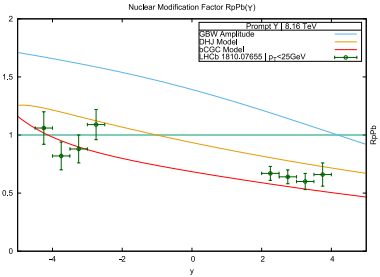

Figure: (b)

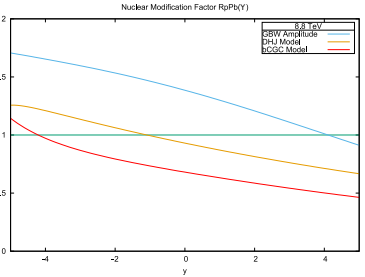

Figure: (c)

- Nuclear modification ratios as function of energy for (a) 5.02 TeV, (b) 8.16 TeV and (c) 8.8 TeV, with LHC data at pPb collision for Υ production;
- The results shows enhancement and suppression up to $\sim 70\%$ and $\sim 50\%$, respectively; the prediction (c) also shows enhancement and suppression up to $\sim 70\%$ and $\sim 50\%$, respectively;

Υ results with LHC energies

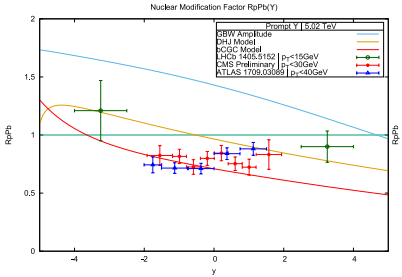

Figure: (a)

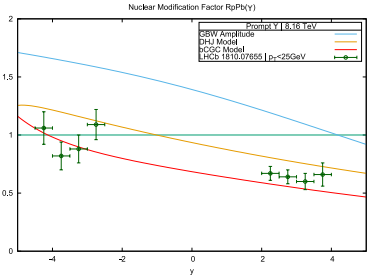

Figure: (b)

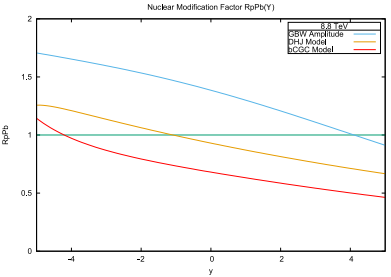

Figure: (c)

- Nuclear modification ratios as function of energy for (a) 5.02 TeV, (b) 8.16 TeV and (c) 8.8 TeV, with LHC data at pPb collision for Υ production;
- The results shows enhancement and suppression up to $\sim 70\%$ and $\sim 50\%$, respectively; the prediction (c) also shows enhancement and suppression up to $\sim 70\%$ and $\sim 50\%$, respectively;

Conclusions

- In general, the nuclear modification factors for J/ψ production have been shown more suppression than Υ case;
- In particular, the bCGC model overestimated the suppression more than other models;
- Further, the evaluation are very sensitive to the saturation scale and another approaches should be analyzed;
- Also, an enhanced study can be made taking into account another theoretical approaches, beyond quasi-classical one.

Conclusions

- In general, the nuclear modification factors for J/ψ production have been shown more suppression than Υ case;
- In particular, the bCGC model overestimated the suppression more than other models;
- Further, the evaluation are very sensitive to the saturation scale and another approaches should be analyzed;
- Also, an enhanced study can be made taking into account another theoretical approaches, beyond quasi-classical one.

Conclusions

- In general, the nuclear modification factors for J/ψ production have been shown more suppression than Υ case;
- In particular, the bCGC model overestimated the suppression more than other models;
- Further, the evaluation are very sensitive to the saturation scale and another approaches should be analyzed;
- Also, an enhanced study can be made taking into account another theoretical approaches, beyond quasi-classical one.

Conclusions

- In general, the nuclear modification factors for J/ψ production have been shown more suppression than Υ case;
- In particular, the bCGC model overestimated the suppression more than other models;
- Further, the evaluation are very sensitive to the saturation scale and another approaches should be analyzed;
- Also, an enhanced study can be made taking into account another theoretical approaches, beyond quasi-classical one.

Thank you!

References I

[1] T. Matsui and H. Satz. J/ψ Suppression by Quark-Gluon Plasma Formation. *Phys. Lett.*, B178:416–422, 1986. doi: 10.1016/0370-2693(86)91404-8.

[2] D. E. Kharzeev, E. M. Levin, and K. Tuchin. Nuclear modification of the J/ψ transverse momentum distributions in high energy pA and AA collisions. *Nucl. Phys.*, A924:47–64, 2014. doi: 10.1016/j.nuclphysa.2014.01.006.

[3] A. Andronic et al. Heavy-flavour and quarkonium production in the LHC era: from proton–proton to heavy-ion collisions. *Eur. Phys. J.*, C76(3):107, 2016. doi: 10.1140/epjc/s10052-015-3819-5.

[4] Johann Rafelski and Berndt Müller. Strangeness production in the quark-gluon plasma. *Phys. Rev. Lett.*, 48:1066–1069, Apr 1982. doi: 10.1103/PhysRevLett.48.1066. URL `https://link.aps.org/doi/10.1103/PhysRevLett.48.1066`.

[5] P Koch, B Müller, and J Rafelski. Strangeness in relativistic heavy ion collisions. *Physics Reports*, 142(4): 167 – 262, 1986. ISSN 0370-1573. doi: https://doi.org/10.1016/0370-1573(86)90096-7. URL `http://www.sciencedirect.com/science/article/pii/0370157386900967`.

[6] Alfred H. Mueller. Soft gluons in the infinite momentum wave function and the BFKL pomeron. *Nucl. Phys.*, B415:373–385, 1994. doi: 10.1016/0550-3213(94)90116-3.

[7] Alfred H. Mueller and Bimal Patel. Single and double BFKL pomeron exchange and a dipole picture of high-energy hard processes. *Nucl. Phys.*, B425:471–488, 1994. doi: 10.1016/0550-3213(94)90284-4.

References II

[8] Alfred H. Mueller. Unitarity and the BFKL pomeron. *Nucl. Phys.*, B437:107–126, 1995. doi: 10.1016/0550-3213(94)00480-3.

[9] F. Dominguez, D. E. Kharzeev, E. M. Levin, A. H. Mueller, and K. Tuchin. Gluon saturation effects on the color singlet J/ψ production in high energy dA and AA collisions. *Phys. Lett.*, B710:182–187, 2012. doi: 10.1016/j.physletb.2012.02.068.

[10] Krzysztof J. Golec-Biernat and M. Wusthoff. Saturation effects in deep inelastic scattering at low Q**2 and its implications on diffraction. *Phys. Rev.*, D59:014017, 1998. doi: 10.1103/PhysRevD.59.014017.

[11] Krzysztof J. Golec-Biernat and M. Wusthoff. Saturation in diffractive deep inelastic scattering. *Phys. Rev.*, D60:114023, 1999. doi: 10.1103/PhysRevD.60.114023.

[12] Adrian Dumitru, Arata Hayashigaki, and Jamal Jalilian-Marian. Geometric scaling violations in the central rapidity region of d + Au collisions at RHIC. *Nucl. Phys.*, A770:57–70, 2006. doi: 10.1016/j.nuclphysa.2006.02.009.

[13] Dmitri Kharzeev, Yuri V. Kovchegov, and Kirill Tuchin. Nuclear modification factor in d+Au collisions: Onset of suppression in the color glass condensate. *Phys. Lett.*, B599:23–31, 2004. doi: 10.1016/j.physletb.2004.08.034.

[14] Kirill Tuchin. Forward hadron production in high energy pA collisions: From RHIC to LHC. *Nucl. Phys.*, A798:61–73, 2008. doi: 10.1016/j.nuclphysa.2007.10.008. [J. Phys.G35,no.5,054001.43(2008)].

References III

[15] H. Kowalski, L. Motyka, and G. Watt. Exclusive diffractive processes at HERA within the dipole picture. *Phys. Rev.*, D74:074016, 2006. doi: $10.1103/\mathrm{PhysRevD.74.074016}$.

[16] R Aaij et al. Study of J/ψ production and cold nuclear matter effects in pPb collisions at $\sqrt{s_{NN}} = 5$ TeV. *JHEP*, 02:072, 2014. doi: $10.1007/\mathrm{JHEP02(2014)072}$.

[17] Roel Aaij et al. Study of Υ production and cold nuclear matter effects in pPb collisions at $\sqrt{s_{NN}}$=5 TeV. *JHEP*, 07:094, 2014. doi: $10.1007/\mathrm{JHEP07(2014)094}$.

[18] R. Aaij et al. Prompt and nonprompt J/ψ production and nuclear modification in pPb collisions at $\sqrt{s_{\mathrm{NN}}} = 8.16$ TeV. *Phys. Lett.*, B774:159–178, 2017. doi: $10.1016/\mathrm{j.physletb.2017.09.058}$.

[19] Roel Aaij et al. Study of Υ production in pPb collisions at $\sqrt{s_{NN}} = 8.16$ TeV. *JHEP*, 11:194, 2018. doi: $10.1007/\mathrm{JHEP02(2020)093}$,$10.1007/\mathrm{JHEP11(2018)194}$. [Erratum: JHEP02,093(2020)].

[20] Betty Bezverkhny Abelev et al. J/ψ production and nuclear effects in p-Pb collisions at $\sqrt{S_{NN}} = 5.02$ TeV. *JHEP*, 02:073, 2014. doi: $10.1007/\mathrm{JHEP02(2014)073}$.

[21] Shreyasi Acharya et al. Inclusive J/ψ production at forward and backward rapidity in p-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 8.16$ TeV. *JHEP*, 07:160, 2018. doi: $10.1007/\mathrm{JHEP07(2018)160}$.

[22] CMS Collaboration. Nuclear modification of Υ states in pPb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV. 2019.

References IV

[23] Morad Aaboud et al. Measurement of quarkonium production in proton–lead and proton–proton collisions at 5.02 TeV with the ATLAS detector. *Eur. Phys. J.*, C78(3):171, 2018. doi: 10.1140/epjc/s10052-018-5624-4.

[24] A. Adare et al. Cold Nuclear Matter Effects on J/ψ Yields as a Function of Rapidity and Nuclear Geometry in Deuteron-Gold Collisions at $\sqrt{s_{NN}} = 200$ GeV. *Phys. Rev. Lett.*, 107:142301, 2011. doi: 10.1103/PhysRevLett.107.142301.