Could partons be accelerated?

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The nuclear modification factor as a function of $p_T$ in the region of $p_T \approx 7 - 50$ GeV/c for the charged particles produced in the most central Pb-Pb collisions at 2.76 A TeV increase almost linearly with a slope predicted for the inverse Compton effect. Around $p_T \approx 60$ GeV/c, a regime change occurs, which is characteristic for the phenomenon. We propose that this phenomenon can be explained by a collective parton group formation (through the appearance of a new string as a result of fusion of strings) in the interval of $5 < p_T < 20$ GeV/c. In the case of a coherent collision with a parton that has a lower energy than the group, the parton can gain energy through the inverse Compton effect, resulting in its acceleration.

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I. INTRODUCTION

The inverse Compton effect (ICE) states that a photon can gain energy in a collision with a more energetic electron, but can this phenomenon occur in a collision between partons? In other words, is there a parton version of ICE? In this paper, we analyze the behavior of the Nuclear Modification Factor ($R_{AA}$) as a function of $p_T$ for charged particles produced in the most central Pb-Pb collisions at energies of $\sqrt{s_{NN}} = 2.76$ TeV (see paper) and propose that parton ICE can be responsible for the behaviour we observe.

II. INITIAL DATA

The figure shows the dependence of the $R_{AA}$ values on $p_T$ for charged particles produced in Pb-Pb collisions (the experimental data were taken from the HEP Data: https://hepdata.net/record/ins1088823) with centrality of 0-5% at energies of 2.76 AGeV. There are several trends observed as $p_T$ increases:
- for $p_T < 2$ GeV/c the values of $R_{AA}$ increase from 0.36 to 0.42;
- for $2 < p_T < 7$ GeV/c the values of $R_{AA}$ decreases to 0.15 and reaches its minimum;
- for $7 < p_T < 40 - 50$ GeV/c the values of $R_{AA}$ increase from 0.15 to 0.6 and reaches its maximum.

Furthermore, at $p_T \approx 50 - 60$ GeV/c, a regime change occurs and the values of $R_{AA}$ remain at 0.6. The behavior of $R_{AA}$ in the interval $7 < p_T < 100$ GeV/c is similar to the behavior of the photon energy distribution under ICE (see appendix).

III. PHYSICAL PICTURE

We believe that the reason for this similarity may be that in the momentum interval $5 < p_T < 20$ GeV/c (this is the second $p_T$ region observed in the paper) partons collide with higher energy objects, and as in the case of a collision of a photon with a higher energy electron, parton ICE occurs. These objects can be parton groups with energy $\gamma_{\text{group}}$ (and with

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mass $m_{\text{group}}$). In the case of a coherent collision of a parton with energy $\alpha_{\text{part}} = \gamma_{\text{part}}$, it can acquire energy $\alpha_{\text{part}} > \alpha_{1\text{part}}$ and accelerate due to parton ICE. The parton group could be formed as a result of strings fusion\(^{6,2}\) in the region of $5 < p_T < 20\text{GeV/c}$ (see paper\(^{3}\)). The strings fusion in dense medium can lead to the formation of new string, is responsible for the parton collective behavior. The last was observed in the RHIC experiments\(^{10,11}\) first time and was confirmed by the LCH data\(^{12}\).

To get some quantitative confirmation of the physical picture we used following function

$$R_0 = \frac{\frac{d^2N}{d\eta d\alpha}}{\frac{d^2N}{d\eta d\alpha}|\alpha = \alpha_1} = \frac{4\gamma^2 \alpha - \alpha_1}{4\gamma^2 \alpha_1 - \alpha_1}$$

or

$$R_0 \simeq \frac{\alpha}{\alpha_1}$$  \hspace{1cm} (2)

for $\gamma >> 1$. The $R_0$ is the energy distribution of photons ($\frac{d^2N}{d\eta d\alpha}$) with energy $\alpha < \alpha_1$ for $\alpha_1 < \gamma$ (see appendix), normalized to the value of $\frac{d^2N}{d\eta d\alpha}$ at $\alpha = \alpha_1$. The values of $R_0$ are compared with $R_{AA}$ (from Figure 1) in the interval $7 < p_T < 50\text{GeV/c}$. In the case of a coherent collision of a parton with energy $\alpha_{1\text{part}} = E_{1\text{part}}/m_{\text{group}} = \gamma_{\text{group}}$ with a group of partons of energy $\gamma_{\text{group}} = E_{\text{group}}/m_{\text{group}} > \alpha_{1\text{part}} >> 1$, partons final energy will be $\alpha_{\text{part}} = E_{\text{part}}/m_{\text{group}}$. The values of $E_{1\text{part}}$ and $E_{\text{part}}$ are much larger than the parton’s rest energy, so we can assume that $E_{1\text{part}} \simeq p_{1\text{part}}$ and $E_{\text{part}} \simeq p_{\text{part}}$ ($p_{1\text{part}}$ and $p_{\text{part}}$ is 3-momentum of parton before and after the collision). For the particles under consideration (see\(^2\)), the values of their pseudorapidity are taken in the interval of $|\eta| < 1$, so we can write $p_{\text{part}} \simeq p_T\text{part}$ ($p_T\text{part}$ is the transverse momentum of the parton after the collision). Therefore, for partons the expression\(^2\) can be rewritten as:

$$R_0 = \frac{1}{\alpha_{1\text{part}}} \frac{\alpha_{\text{part}}}{E_{\text{part}}} \simeq \frac{1}{E_{1\text{part}}}$$

$$\simeq \frac{1}{p_{1\text{part}}} \frac{p_{\text{part}}}{p_T\text{part}}$$

To determine $p_{1\text{part}}$ from\(^8\) we used the fact that at the point of regime change $p_{1\text{part}} = p_{\text{part}} \simeq p_T\text{part}$. Visually, the regime change seems to be near $p_T \simeq p_T\text{part} \simeq 40 - 50\text{GeV/c}$. To obtain a more accurate value we fitted the $R_{AA}$ data with the linear function $y = ax$ in the region of $6 < p_T < 70\text{GeV/c}$, changing the minimum and maximum values of the $p_T$ intervals to obtain the best fitting results. The Table shows three best fitting
TABLE I. The fitting results

| The values of $p_T$ (GeV/c) | $\chi^2/ndf$ | Prob.          | $a$        |
|-----------------------------|-------------|----------------|------------|
| 8.4 – 38.4                  | 3.526/7     | 0.8325         | 0.0162 ± 0.0007 |
| 8.4 – 44.8                  | 7.453/8     | 0.4886         | 0.0158 ± 0.0007 |
| 8.4 – 54.4                  | 16.85/9     | 0.05108        | 0.0154 ± 0.0006 |

results. The fit function $y = ax$ seems to describe the $R_{AA}$ data well in the interval of $p_T = 8.4 – 44.8$GeV/c, whereas after $p_T = 54.4$GeV/c is turned on it deteriorates fast. This means that the transition point is near the value $p_T = 55.4 ± 6.4$GeV/c and it can be assumed that $p_{1part} ≃ 60$GeV/c and the value $1/p_{1part} ≃ 0.0167$ and $R_0 = 0.0167p_T$. The solid line in the figure shows the behavior of $R_0$ as a function of $p_T$ which well describes the $R_{AA}$ in the region $7 < p_T < 50$GeV/c. This is understandable since the slope of the line for $R_0 = 0.0167p_T$ almost exactly coincides with the slope of the line ($a = 0.0162 ± 0.0007$) obtained for the best fitting of the experimental data on $R_{AA}$ (see Table of the values of $a$).

The definition of $R_0$ tells us that at the regime change point the value of $R_0$ would be 1, but in the experiment the $R_{AA}$ values remain constant around 0.6 – 0.7 in the region of $p_T > 60$GeV/c. One explanation for this difference could be the parton energy loss, which was not taken into account in the calculation of $R_0$. Returning back to the interval $\alpha < \alpha_1$, we should note that the agreement between the slope values of $R_{AA}$ behavior as a function of $p_T$ and of $R_0$ in this interval may indicate that the parton energy loss (parton suppression effect\textsuperscript{13,14}) almost does not change the slope for $R_{AA}$ in this region.

IV. CONCLUSION

We conclude that the values of $R_{AA}$ as a function of $p_T$ in the interval $7 – 50$GeV/c increase almost linearly with a slope predicted for the parton ICE. At $p_T ≃ 60$GeV/c a regime change occurs, which is characteristic for this effect. These results indicate that partons can be accelerated by ICE. We assume that this can be due to the collective effects associated with the fusion of strings and the appearance of new strings in the dense medium. In the case of a coherent collision with a parton that has a lower energy than the new string, the parton can gain energy and accelerate, transitioning into $p_T > 20$GeV/c interval. After losing a significant part of its energy new string will decay into partons with lower energies in the interval $p_T < 2$GeV/c. This can cause an anomalous suppression of partons in the $2 < p_T < 20$GeV/c interval.

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V. APPENDIX

In the approximate formulas are given for the energy distributions of photons $\frac{d^2N}{dtd\alpha}$ in the case of ICE. It is shown that if a photon with energy $\alpha_1 = E_1/m_e$ (in units of electron mass $m_e$, $E_1$ is the energy of photon) collides with an electron with energy $\gamma = E_e/m_e$ ($E_e$ is the electron energy) and receives energy $\alpha = E/m_e$ (E photon energy), then the energy
distribution of photons after a collision can be written in the form:

\[
d^2N \approx \frac{\pi r_0^2 c}{2\gamma^4\alpha_1} \left( \frac{4\gamma^2\alpha}{\alpha_1} - 1 \right)
\]

in the energy interval \(\alpha_1/4\gamma^2 \leq \alpha \leq \alpha_1\) and in the form:

\[
d^2N \approx \frac{2\pi r_0^2 c}{\alpha_1\gamma^2} \times \left[ 2q^* \ln q^* + (1 + 2q^*)(1 - q^*) + \frac{1}{2} \left( \frac{4\alpha_1\gamma q^*}{1 + 4\alpha_1\gamma q^*} \right) (1 - q^*) \right]
\]

\[
q^* = \frac{\alpha}{4\alpha_1\gamma^2(1 - \frac{q^*}{\gamma})}
\]

in the energy interval \(\alpha_1 \leq \alpha \leq 4\gamma^2\alpha_1/(1 + 4\gamma\alpha_1)\), where \(r_0\) is the classical radius of the electron. From these formulas it is clear that for values of \(\alpha = \alpha_1\), a change in the regime will be observed in the behavior of \(\frac{d^2N}{dtd\alpha}\).

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