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RING TYPE EVENTS AND NUCLEAR COLLISION AT SPS ENERGIES AND NUCLEAR REFRACTIVE INDEX

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In this paper we performed analyses of the data obtained of various ring-like events obtained from ultra relativistic nuclear interactions of ^{32}S–AgBr at 200 AGeV, ^{208}Pb–AgBr at 158 AGeV and ^{197}Au–AgBr at 11.6 AGeV in the light of Cherenkov Radiation as proposed by Dremin. The refractive index of the nuclear medium is calculated from the knowledge of incident beam energy and cone angle of radiation. This study reveals values of the refractive index of the nuclear medium different from values of nuclear medium obtained for RHIC data.

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1. Introduction

Studying or probing highly excited nuclear dense matter under controlled conditions in the laboratory has proven their worth in exploring the nature of matter in extreme conditions of temperature and density. Under such extreme conditions a new form of matter called Quark Gluon Plasma (QGP) is created. In this state normal forces that confine quarks and gluons in an individual hadron is overcome to form QGP.

According to a new idea of multiparticle production at high energies, when a hadron passes through a nuclear active medium (a nucleus or a nucleon) it may emit coherent hadronic radiation (pions) when its velocity is greater than the velocity of emission in the medium. This effect is analogous to that of Cherenkov electro magnetic radiation of photons, which are emitted by a bunch of electrons traversing a medium whose refractive index exceeds unity. For the electro magnetic Cherenkov radiation the photons are emitted at a definite angle

$$\cos\theta = \frac{1}{\beta n}\,, \tag{1}$$

where n is the refractive index of light in the medium and $n > 1$. $\beta = v/c$ and v is the velocity of the electron.

An illuminated ring is observed in a plane perpendicular to the axis of motion of the electrons. The radius of the ring is determined by the condition (1).

The production of Cherenkov gluons can be explained if we treat an impinging nucleus as a bunch of confined quarks each of which can emit gluons when traversing in a target nucleus. This also leads to the interpretation that Cherenkov gluons are obtained in ultra-relativistic nuclear interaction.

2. Cherenkov radiation and ring-like patterns

It was first observed in cosmic ray events [1–3] that two rings with an enhanced density of particles existed in the target diagrams of the event. This observation suggested that hadronic radiations have possible Cherenkov characteristics [4–6]. Later, analysis of the particles produced in ultra-relativistic nuclear collisions [7] have proved sporadic occurrences of large fluctuations in the pseudorapidity distribution which manifest themselves as peaks often called spikes in the narrow pseudorapidity interval. These events when plotted in η–ϕ target diagram form spectacular ring-like patterns. At very high energies the number of Cherenkov gluons can be large and they form a ring in a single event. If one or few gluons are emitted in an event, the rings can be detected only in high statistics experiments as peaks in the pseudorapidity distribution. The ring-like patterns may be an indication of the direction of the emitted Cherenkov gluons.

The pseudorapidity density of the events in the spike zone is very high and is enough to produce energy density higher than the critical density. This may be interpreted as possible signature of QGP also.

From (1) we can find the angle of emission of the gluon. If this angle is denoted by θ, then

$$\theta = \cos^{-1}\left(\frac{1}{\beta n}\right)\,, \tag{2}$$

where n is the refractive index of the nuclear medium, and the value of β can be obtained for a particular collision.

Also, the pseudorapidity η for a particular event is related to θ by,

$$\eta = -\ln\left(\frac{\tan\theta}{2}\right)\,. \tag{3}$$

Thus, by knowing the values of β and η we can obtain the refractive index of the nuclear medium. In RHIC experiments, for two nuclei colliding, two bumps are supposed to occur in the pseudorapidity distribution. Since, any of the colliding nuclei can be treated as a bunch of partons, two cones in the opposite hemispheres in c.m.s. may be observed.

In fixed target experiments we can observe emission of rather soft Cherenkov gluons by very high energy partons corresponding to resonance regions for hadrons. It results in two peaks in the deep forward and backward fragmentation regions of the pseudorapidity distribution. These peaks are unobservable in collider experiments because particles are captured inside the accelerator ring [6].

Recently, we reported the result of some ring-like events have been obtained experimentally (by searching) [8]. In this paper we report the detailed study of ring-like events in ^{32}S–AgBr interaction at 200 AGeV and the data of central experimental ^{208}Pb–AgBr and 197 Au–AgBr interactions using a different technique to be explained later. In each case we have calculated the refractive index of the nuclear medium. The data of the central experimental ^{208}Pb–AgBr and ^{197}Au–AgBr interactions have been obtained from [9].

3. Experimental details

The present analysis is based on interactions of a ^{32}S beam with emulsion nuclei at 200 AGeV. A stack of Illford G5 emulsion pellicles of dimensions $18 \times 7 \times 0.06$ cm^3 was exposed horizontally to a ^{32}S beam with energy 200 AGeV at the CERN SPS. Flux density of the incident particles was 1×10^3 particles per cm^2. Here we are dealing with nuclear emulsion detector which is itself the target for any high energy projectile beam. A Leitz Metalopan microscope with a 10X objective and 10X ocular lens provided with a semi-automatic scanning stage is used to scan the plates. The interactions have been picked up after 1 cm from the leading edge of the plate. Each interaction was scanned using the "along-the-track" method with the help of a microscope.

To reduce the loss of tracks as well as to reduce the error in the angle measurement we excluded events that occurred within 20 μm from the top or bottom surface of the pellicle. Great care was taken in the identification of different tracks.

All primary beam tracks were followed back to ensure that the events chosen did not include interaction from the secondary tracks of other interactions. The primaries originating from other interactions were observed and the corresponding events were removed from the sample.

For the present study only shower particles produced in the interaction are investigated. (The relativistic shower tracks with ionization $I \leq 1.4\, I_0$ are mainly produced by pions and are not generally confined within the emulsion pellicle. These shower particles have energy in the GeV range.)

According to the above selection procedure we had chosen 140 events of ^{32}S–AgBr interactions at 200 AGeV. The emission angle (θ) is measured for each track with respect to the beam direction by taking readings of the coordinates of the interaction point (X_0, Y_0, Z_0), coordinates (X_1, Y_1, Z_1) at the end of the linear portion of each secondary track and coordinate (X_i, Y_i, Z_i) of a point on the incident beam. In the case of pions the variable used is pseudorapidity and defined as $\eta = -\ln(\tan\theta/2)$, where θ is the emission angle with respect to the beam direction. For emulsion tracks with exposures parallel to the emulsion plates, the uncertainty in the measurement of emission angles, which is very essential, for this study never exceeds a few mrad corresponding to a resolution of 0.1 units in the pseudorapidity.

As has been mentioned earlier, the central experimental ^{208}Pb and ^{197}Au induced interactions with AgBr target nuclei in emulsion detector at 158 AGeV and 11.6 AGeV is obtained from [9], where photo emulsion technique is used; the details of which can be found in [10,11].

4. Methodology of separation of ring-like and jet-like events

From the azimuthal distribution of pions and the classes of substructures thus obtained, each consecutive n_d tuple of particles along the η-axis is considered as a group characterized by $\Delta\eta_c$ and $\rho_c = n_d/\Delta\eta_c$. Dense group can then be defined and recorded as above. This method has the advantage that all groups, including the discarded, more dilute ones, have by definition the same multiplicity n_d, and can be readily compared [11]. With this method it is also a fairly simple task to compare the obtained sample with samples obtained by a purely stochastic process as well as samples obtained from model-based Monte Carlo calculations.

Next we need to parameterize the azimuthal structure in a suitable way, so that large values of the parameter represent one type of structure and small values the other. Two sums have been suggested as such parameters and are given by

$$S_1 = -\sum \ln(\Delta\Phi_i) \qquad \text{and} \qquad S_2 = \sum (\Delta\Phi_i)^2 .$$

where $\Delta\Phi_i$ is the azimuthal difference between two neighboring particles in the group. (Starting from the first and second and ending from the last and first.) For the sake of simplicity we can count $\Delta\Phi$ in units of full revolutions and thus we have

$$\sum(\Delta\Phi_i) = 1 .$$

Both these parameters will be large ($S_1 \rightarrow \infty$, $S_1 \rightarrow 1$) for jet-like structures and small ($S_1 \rightarrow n_d$, $S_2 \rightarrow 1/n_d$) for ring-like structures. S_2 distribution is used to separate ring-like and jet-like events. From the $S_2/\langle S_2\rangle$ distribution of the data we separate ring-like and jet-like events taking into account that for ring-like events $S_2/\langle S_2\rangle$ is less than 1. Whereas, for jet-like events $S_2/\langle S_2\rangle$ is greater than 1. The distribution of $S_2/\langle S_2\rangle$ for ^{32}S–AgBr interactions at 200 AGeV shows a peak at 0.60. We consider ring-like structured events having $S_2/\langle S_2\rangle$ in the range 0.3–0.7.

5. Results and discussion

Five ring-like events in particular having high multiplicity ($N > 170$) and showing two distinct peaks in the pseudorapidity distribution were chosen for the study. The values of the rapidity from each of the peaks is obtained and the corresponding values of the cone angle θ is calculated. For the five ring-like events of our data (^{32}S–AgBr interaction) the two peaks are obtained for each event multiplicity; one in the range $\eta = 1.5$–2.5 and the other in the range $\eta = 3.0$–4.5. The centre of mass rapidity ($\eta_{\rm c.m.}$) for ^{32}S–AgBr interaction, assuming each interaction as an entirely incoherent set of 32 independent nucleon–nucleon collision, is 3.03. On the other hand, if the ^{32}S nucleus interacts as a single coherent object with an Ag or Br nucleus, then the corresponding centre of mass rapidities shall have values 2.425 and 2.573, respectively. The values of the $\eta_{\rm c.m.}$ are lying between the two rapidity values where the peaks are obtained in the fixed target experiment, as shown in Table I. Along with our data we also analysed the data of [9] for calculating the refractive index of the nuclear medium which are the data of central experimental ^{208}Pb–AgBr and ^{197}Au–AgBr interactions. The rapidity distributions for ring-like subgroups obtained from [9] have been investigated. From the rapidity distribution of ^{208}Pb–AgBr at 158 AGeV, it is observed that two peaks, one in the range $\eta = 1.6$–3.2 and the other in the range

TABLE I

Table for calculation of n for ^{32}S–AgBr interaction at 200 AGeV.

Multiplicity	Peak 1				Peak 2			
of events	rapidity	θ	$\cos\theta$	R.I.(n)	rapidity	θ	$\cos\theta$	R.I.(n)
229	2.2	12.65	0.98	1.02	3.4	3.82	0.99	1.01
228	2.2	12.65	0.98	1.02	4.4	1.41	0.99	1.01
202	2.2	12.65	0.98	1.02	3.8	2.56	0.99	1.01
190	2.2	12.65	0.98	1.02	4.2	1.72	0.99	1.01
171	2.2	12.65	0.98	1.02	4.2	1.72	0.99	1.01

$\eta = 3.6$–5.2, occur (the center of distribution is $\eta \approx 3.5$). On the other hand, for ^{197}Au–AgBr at 11.6 AGeV interaction again two peaks are obtained, one at $\eta = 1.2$–2.0 and the other at $\eta = 2.2$–3.0 (the center of distribution is $\eta \approx 2.2$). The mean of the η values for ^{208}Pb–AgBr and ^{197}Au–AgBr interactions have been used for obtaining the values of the cone angle θ.

Using the concept of Cherenkov gluon radiation we calculate the nuclear refractive index from the knowledge of ring-like events. The data obtained from various ring-like events in ultra relativistic nuclear interactions of ^{32}S–AgBr at 200 AGeV, ^{208}Pb–AgBr at 158 AGeV and ^{197}Au–AgBr at 11.6 AGeV were analyzed and from the knowledge of the incident beam energy and the cone angle of the radiation we calculated the refractive index of the nuclear medium which are shown in Table I, II and III, respectively for different projectiles and energy ranges. From the calculated values of the refractive index of the nuclear medium we also attempt to investigate the possibility of phase transition from a normal hadronic phase to a QGP phase.

TABLE II

Table for calculation of n for Pb–AgBr interaction at 158 AGeV.

Peak 1				Peak 2			
Rapidity	θ	$\cos\theta$	R.I.(n)	Rapidity	θ	$\cos\theta$	R.I.(n)
3.9	2.319	0.99	1.01	4.9	0.853	0.99	1.01

TABLE III

Table for calculation of n for Au–AgBr interaction at 11.6 AGeV.

Peak 1				Peak 2			
Rapidity	θ	$\cos\theta$	R.I.(n)	Rapidity	θ	$\cos\theta$	R.I.(n)
1.6	22.83	0.922	1.09	2.6	8.496	0.99	1.01

The values of refractive index obtained from all the interactions as shown in Table I, II and III, respectively, are close to unity. It is interesting to note that the nuclear refractive indices calculated here have much different values from the nuclear refractive index values obtained from the RHIC data ($n \approx 3$) [15–19].

6. Conclusions

Analysis of large set of data in terms of Cherenkov gluons as proposed by Dremin may strengthen the idea that ring-like substructures have appeared due to an effect analogous to Cherenkov light. Similar inference has been obtained in [9,20].

The values of the so-called nuclear refractive index extracted from the data are found to be close to unity in all the cases which is different from the nuclear refractive index values obtained from RHIC data.

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