CHAPTER II

Experimental Technique
2.1 Introduction

To study the hadron-nucleus and nucleus-nucleus collisions at relativistic energies, nuclear emulsion is preferred due to its higher capabilities in comparison to bubble chamber and counters. Nuclear emulsion serves as detector as well as target. It is a versatile instrument to detect charged particles and is capable of giving information about their masses, energies, modes of interaction and decay. Information recorded in the form of photograph of the collisions after developing the emulsion stack can be stored for many years by keeping the stack under specified conditions. It is a $4\pi$ detector having good spatial resolution and is quite suitable to measure particles' multiplicities and their space angles, azimuthal angles etc.

The composition of nuclear emulsion is heterogeneous. It consists of three basic components: (a) crystals of silver halide, mostly bromide with small admixture of iodine, (b) gelatin and glycerin and (c) water. Glycerin is used as plasticizer, to reduce the brittleness of the emulsion. The compositions of different groups of nuclei in emulsion are such that for $p$-Emulsion collisions about 71% of the collisions occur with heavy nuclei group, AgBr, 25% with light nuclei group ($CNO$) and 4% with hydrogen nuclei [1]. However, for nucleus-nucleus collisions, these number change with the mass of the projectile. The average mass number $<A>$ of nuclei of different groups may be obtained from the equation

\[
<A> = \frac{\sum N_i A_i}{\sum N_i}
\]

where $A_i$ and $N_i$ represent mass number and the number of atoms of $i$th element respectively present in a particular group. The average mass numbers $<A>$ of H, CNO and AgBr group of nuclei are 1, 14 and 94 respectively.

When a charged particle traverses through a medium, it excites and ionizes the atoms of the medium due to the coulomb interactions. This results in the loss of energy of the charged particle. If a particle of charge $Ze$ and mass $M$ traverses with velocity $v$ in a medium of atomic number $z$ and mass number $A$, then the rate of energy loss $dE$ per unit length $dx$ traversed is given by the Bethe’s formula:

\[
\frac{-dE}{dx} = \frac{4\pi^2 Z^2 e^4}{m_e v^2 A} N\left[ z \left\{ \ln \left( \frac{2 m_e v^2}{I (1 - \beta^2)} \right) - \beta^2 \right\} - C_k \right],
\]
where minus sign indicates loss of energy, $\beta = v/c$, $N$ is the number density of the medium, $I$ is the mean ionization potential and $m_e$ is the mass of the electron. $C_k$ denotes the correction factor in case the velocity of the incident particle is comparable with that of the $k$-shell electron. For a heterogeneous medium like emulsion, the above relation is modified to

$$\frac{-dE}{dx} = \frac{4\pi^2 Z^2 e^4}{m_e v^2 A} \sum_i N_i \left[ z_i \left\{ \ln \left( \frac{2 m_e v^2}{I_i (1 - \beta^2)} \right) - \beta^2 \right\} - C_k \right], \quad 2.3$$

where $i$ refers to different elements present in the emulsion. It is clear from Equation 2.3 that energy loss does not depend on mass $M$ of the charged particle. Since the logarithmic term varies only slightly with $v$, the rate of energy loss is directly proportional to the square of the charge ($Ze$) of the particle and is inversely proportional to the square of its velocity.

Energy lost by the charged particle while passing through emulsion is transferred to the atomic electrons. As a result, the atom goes to an exited state. If the energy gained by the electron is greater than its ionization potential energy then electron becomes free and is librated from the atom. The atom is ionized and the formation of latent image along the path of particle takes place due to the ionization of silver atoms by interactions of the charged particle with silver halide grains. The mechanism of formation of latent image was first explained by Gurney & Mott [2,3]. On immersing the emulsion in a reducing bath, called developer, electrons are transferred from the molecules of developer to the latent images. The interstitial silver ions are then attracted from the body of the crystal and deposited on the latent image specks. In other words, the ionization of the atom changes some of the halide grains in such a way that they, when immersed in a developer, get converted into silver grains, which may easily be distinguished because of their black colour. After the development, the emulsion is put in a fixer, which dissolves all the undeveloped grains while leaving the developed grains unaffected. Due to removal of undeveloped grains a reduction in the thickness of the emulsion take place, which is known as shrinkage. This has to be taken into account while doing the calculations. After fixing, the emulsion is washed and then dried. A series of black grains is formed which is the track of the particle. The number density of the grains forming the track of a charged particle depends on the nature, charge and velocity of the particle. From Equation 2.3 it is
clear that the rate of energy loss is inversely proportional to the square of velocity. As a result, at high velocity small number of grains is formed and vice versa. If the charge of the particle is large, the rate of loss of energy is large, as a result the number density of grains is also large and vice versa. Particles of different ionizing powers produce tracks with different grain densities and thus they appear quite different. The nuclear emulsion has high density and stopping power, about 1700 times the stopping power of standard air. Thus many short-lived particles can be brought to rest in emulsion before they decay.

There are some drawbacks with nuclear emulsion also. As the number of grains developed depends on the charge of the particle passing through the medium, no grain is formed when a neutral particle passes through the emulsion and thus neutral particles cannot be detected in emulsion. Further, the emulsion technique is very slow and it requires a special dark room processing and very careful handling before development. Shielding from the background radiation is necessary. To maintain the shape and rigidity of the stack, it should be kept at low temperature that is below the melting point of gelatin, which is about 45°. The other drawback of emulsion is that the identification of the target nucleus is not precise.

2.2 Scanning

The process of searching the positions of collisions in the emulsion pellicles is called scanning. The scanning can be performed in two ways: (i) area scanning and (ii) line scanning. In the following sections we discuss these two types of scanning in detail.

2.2.1 Area Scanning

In this type of scanning the upper or lower surface of emulsion pellicle is set in the field of view of the microscope and the positions of collisions in this field of view are recorded. After that next layer of the pellicle is focused in the field of view by rolling the fine focus of the controlled z-motion of the microscope and positions of collisions are recorded. This process is repeated again and again till the full depth of the pellicle is scanned. The field of view is then shifted along the $X$ (or $Y$) motion of the microscope until the whole $X$ (or $Y$)–strip of the pellicle is scanned. After that, the field of view is then shifted to the next $X$ (or $Y$)–strip. In this way the whole emulsion pellicle is scanned.
This method is considerably faster than the line scanning, but there is a chance to miss the collisions having small number of tracks.

2.2.2 Line Scanning

This method of scanning is preferred when a parallel beam of particles is incident perpendicular to the surface of one edge of emulsion stack that is called leading edge and pass parallel to the surface of emulsion pellicle and may leave the opposite side of the stack. In this method, first a primary track is picked up at the leading edge of the emulsion pellicle and is followed until it interacts in emulsion or leaves the pellicle. Similarly all the primary tracks are picked up one by one and followed until they interact or leave the pellicle. Locations of all the primary collisions are recorded. The line scanning is effective in the following conditions of exposure:

- The flux of the beam is not dense and is spread out through out the leading edge.
- The available length for the traversal of beam is large, that is, the beam does not dip much.

2.3 Track Parameters and their Measurements

There are some parameters like range, ionization, grain density, blob density, blob and gap densities and delta ray density, which are used for the identification of a particle and estimation of its energy.

2.3.1 Range

The distance traversed by a charged particle in the unprocessed emulsion before its kinetic energy reduces to zero is called the range of the particle \( R \) and is given as

\[
R = \frac{E_0}{\int_{0} dE / (\text{dE/dx})}
\]

where \( E_0 \) is the initial kinetic energy of the particle and \(-dE/dx\) represents the rate of energy loss of the particle. But during the development of emulsion stack, the shrinkage and distortion affect the particle range. Therefore these effects must be taken into consideration while computing the true range.
2.3.2 Grain Density

The track of a particle in emulsion appears as minute trails of black grains. The number of grains per unit length is known as grain density. Grain density is found to be a reliable parameter for estimating the ionization caused by a particle. However, the grain density of a track corresponding to the particular value of ionization depends on the degree of development of emulsion. For accurate results the relative grain density \( g^* \) of the track of the particle is determined by the relation

\[
\frac{g^*}{g_0} = \frac{g}{g_0}
\]

where \( g \) is the grain density of the track of the particle and \( g_0 \) is the grain density of singly charged relativistic particles in the same emulsion. The grain density is proportional to the ionization loss per unit length, that is,

\[
g \propto \frac{dE}{dx} \propto \frac{Z^2}{\beta^2} f(\beta)
\]

For singly charged relativistic particles, \( Z=1 \), therefore

\[
g_0 \propto \frac{1}{\beta^2} f(\beta).
\]

The value of the parameter \( g_0 \) has been determined by measuring the grain density of a number of tracks of singly charged relativistic particles.

2.3.3 Blob Density

If the velocity of the particle is not very large, the grain density of the track of the particle is large. As a result some of the grains in the track are clogged together. A group of unresolvable grains is called blob. The counting of the number of grains in a blob is very difficult. Therefore, the number of individually resolved blobs is counted without estimating the number of grains in the blobs.

Fowler and Perkins [4] suggested the following empirical relation between the blob density \( B \) and the grain density \( g \)

\[
B = g \exp(\alpha g),
\]
where $\alpha$ is a parameter which depends on the average grain size and optical resolution of the microscope.

2.3.4 Blob and Gap Density Method

The blob and gap density method is used for estimating the ionization of charged particles having small velocities. A blob is defined as a cluster of grains with no gap visible between them and the length of the gap ($L$) is defined as the distance between inside edges of two neighbouring blobs.

This method was first introduced by Ceallaigh [5] and latter on extended by Fowler and Perkins [4]. It is based on the fact that gap lengths have an exponential frequency distribution for widely different values of specific ionization that can be written as

$$H(L) = B \exp(-gL), \quad \text{2.9}$$

where $H(L)$ denotes the density of gaps of length greater than $L$ and $B$ is the blob density. It was shown by Fowler and Perkins [4] that the coefficient $g$ of the exponential is a good measure of the ionization of the track. If $H_1$ and $H_2$ denote densities of gaps having length greater than gaps $L_1$ and $L_2$ respectively, then the coefficient $g$ can be determined from the following relation,

$$g = \frac{1}{L_2 - L_1} \ln \left( \frac{H_1}{H_2} \right). \quad \text{2.10}$$

2.3.5 Delta Ray Density Method

In general, the energies of the ejected electrons from the atoms due to the coulomb interactions with the charged particle passing through the emulsion are very low, but sometimes the energy gained by the ejected electron is greater than the critical value ($\approx 5KeV$). These electrons are able to travel through several crystals and ionize them. As a result, small tracks of these electrons are formed, which are known as $\delta$-rays. Information regarding the charge of a particle can be obtained by measuring $\delta$-ray density along its trajectory. The $\delta$-ray density depends on the resolution of the emulsion, its sensitivity, convention used, charge and velocity of the moving particle. Certain conventions are adopted for counting the number of $\delta$-rays associated with the track of a charged particle.
Dainton et al [6] defined a track as a $\delta$-ray if it contained at least four grains, while Tidman et al [7] defined a grain configuration as a $\delta$-ray if it had a projected range of at least $1.58\mu m$ on the plane of the emulsion from the axis of the track. The number of collisions per unit length in which the energy transfer exceeds the critical value, that is $\delta$-ray density, is given by

$$n_{\delta} = \text{constt.} Z^2$$  \hspace{1cm} 2.11

where $Z$ is the charge of the particle. If $Z=1$

$$n_{\delta} = \text{constant}.$$  \hspace{1cm} 2.12

Thus the value of the constant can be obtained empirically by counting $\delta$-rays per unit length along the track of a singly charged relativistic particle. The charge of other relativistic particles can be obtained using Equation 2.11.

### 2.4 Classification of Secondary Particles

Secondary particles produced in each collision are classified by determining their energy loss in emulsion. This is done by counting the number of grains over a certain length ($\sim 100\mu m$). The normalized grain density is defined as $g^* = g/g_0$, where $g$ is the observed grain density of the track of the particle and $g_0$ is the grain density of a track caused by a relativistic singly charged particle such as electron or proton. Therefore, the secondary particles produced in the collision are classified as shower, grey, black particles and projectile fragments according to the following standard emulsion criteria:

- **Shower particles**: These are singly charged relativistic particles with relative ionization $g^* < 1.4$. The ionization cut corresponds to the particles’ velocities $\geq 0.7c$. These are produced particles (mainly pions) with energies greater than $400\ MeV$. Their number is denoted as $N_s$.

- **Grey particles**: These are the particles with relative ionization $1.4 \leq g^* < 10$ and range in emulsion $L > 3\ mm$. This corresponds to the particles’ velocities in the interval $0.23c$ to $0.7c$. They are singly charged particles. These particles are mainly protons from the target having energies in the range $26\ MeV - 400\ MeV$. Their number is denoted as $N_g$.

- **Black particles**: These are the particles with relative ionization $g^* \geq 10$ and the range $L \leq 3\ mm$. These are the spectator target protons with energies less than $26\ MeV$ and multi-charged target fragments. Their number is denoted as $N_b$. 
• **Projectile Fragments**: These are fragments of projectile nucleus with range $Z \geq 2$ and have the same momentum per nucleon as the projectile nucleus. The ionization of the fragments remains constant over a wide range but changes with their charges. They are collimated in a narrow cone in the forward direction and can be very easily separated from the target fragments. Their number is denoted as $N_f$.

### 2.5 Angle Measurement of Secondary Particles

Except some shower particles and projectile fragments, the tracks of secondary particles are generally well separated and projected and dip angles are measured directly with the help of the gnomometer and by $Z$-motion of the microscope. The coordinate method is used for angle measurement of the tracks which are not well separated or are collimated in a narrow cone in the forward direction.

#### 2.5.1 Projected Angle

To measure the projected angle $\theta_p$, the primary track of the collision (star) is aligned parallel to the $X$-motion of the microscope. The vertex of the collision is focussed at the center of the graticule of the gnomometer. Now the primary beam track is aligned with one of the reference line of the gnomometer. After that by rotating the gnomometer, the secondary tracks are aligned one by one and gnomometer reading are taken for the projected angle with respect to the reference line.

In the coordinate method, the vertex of the collision is focussed at the center of the graticule of the gnomometer and readings of $X$-motion, $Y$-motion and $Z$-motion of the scale (say $X_0$, $Y_0$, $Z_0$) are taken. The stage is then moved forward to at least ten fields of view following the track very carefully. A point on the track is focussed and readings of $X$, $Y$ and $Z$ motion (say $X_i$, $Y_i$, $Z_i$) are taken. Then the projected angle $\theta_p$ is calculated using the following relation

$$\theta_p = \tan^{-1} \left( \frac{\Delta Y}{\Delta X} \right)$$

where $\Delta X = X_i - X_0$ and $\Delta Y = Y_i - Y_0$. 

2.5.2 Dip Angle

In this method the track, for which the dip angle is to be measured, is aligned along the scale of eyepiece graticule. The dip is measured by moving the Z-motion of the microscope with respect to the dip of the star's vertex for a projected length $L$ of the track in $X$-$Y$ plane. Now the dip angle is calculated by using the relation

$$
\theta_d = \tan^{-1}\left( S \frac{\text{dip}}{L} \right)
$$

where $S$ is the shrinkage factor. In terms of the coordinates

$$
\theta_d = \tan^{-1}\left( S \frac{\Delta Z}{L} \right)
$$

where $L = \sqrt{\Delta X^2 + \Delta Y^2}$.

2.5.3 Space Angle

It is the angle of the secondary track with respect to the forward direction of the primary track. It is calculated using the relation

$$
\cos \theta = \cos \theta_p \times \cos \theta_d
$$

where $\theta$ denotes the space angle.

2.5.4 Azimuthal Angle

This is the angle of projection of the secondary track in the $Y$-$Z$ plane with respect to the $Y$-axis and can be calculated using the following relation

$$
\cos \varphi = (\sin \theta_p \times \cos \theta_d)/ \sin \theta
$$

2.6 Rapidity Variable

Rapidity ($Y$) is a useful parameter in the study of relativistic nucleus-nucleus collisions. It is defined as

$$
Y = \tanh^{-1}(\beta_L)
$$

$$
Y = -\frac{1}{2} \ln \frac{1 + \beta_L}{1 - \beta_L}
$$

where $\beta_L$ is the velocity of the particle along the incident beam. For relativistic particles (like pions) emitted after the collision, the rapidity is approximated by a parameter, which
is known as pseudorapidity ($\eta$) variable. Using Equation 2.19 and taking approximations for relativistic particles, we get

$$ Y \to \eta = -\ln \tan \frac{\theta}{2} $$  \hspace{1cm} 2.20

where $\theta$ is the space angle. The advantage of transforming the rapidity into pseudorapidity is that it is a measurable quantity. But the rapidity cannot be measured in emulsion experiments.

2.7 Theoretical Models of Nucleus-Nucleus Collisions

Various models have been proposed [8-21] to describe the mechanism of particle production and to find as to how various parameters of the system behave during the multiparticle production in high energy nucleus-nucleus collisions. Different models describe different aspects of the collision and are used to explain the experimental results. To find the signals of phase transition that is expected in relativistic nucleus-nucleus collisions, some event generators like FRITIOF, UrQMD etc. have also been developed to simulate nucleus-nucleus collisions. All these event generators assume no Q.G.P. formation and help in understanding the background signals. In the following sections, some of these models and event generators are briefly described.

2.7.1 Participant - Spectator Model

This model is very simple and shows good agreement with experimental data. According to this model, during a nucleus-nucleus collision some nucleon groups, which are located in the overlapped regions of the projectile and target, will just pass through keeping their initial velocities. These nucleon groups are called spectators. On the other hand, in the overlapped region, nucleons interact violently with each other and it is assumed that projectile participants transfer all of their momentum to the effective centre of mass system of all the participant nucleons forming a fireball, which moves forward in the laboratory frame at a velocity intermediate between those of the target and the projectile. This picture is called the participant spectator or fireball model [22] and the three regions produced are known as the participant region, the projectile spectator region and the target spectator region. The energy density in the fireball is extremely high and consequently, it may be treated as an ideal gas, whose properties may be determined by
the laws of thermodynamics. If $A_T$ and $A_P$ represent the number of nucleons in the target and projectile nucleus respectively, the geometrical cross section is given by

$$\sigma_g = \pi r^2 \left(A_T^{1/3} + A_P^{1/3}\right)^2$$  \hspace{1cm} 2.21

where $r_0 = 1.0 - 1.2 \text{ fm}$. If a proton inside the projectile hits the target, it falls in the participant group, otherwise remains as a spectator. Therefore, the average number of participant protons from the projectile nucleus is approximately given by $Z_{proj}$ (number of protons in the projectile nucleus) times the ratio of the target cross section to the geometrical cross section ($\sigma_g$), given as [23,24]

$$\left\langle Z_{\text{part}}^{\text{proj}} \right\rangle = Z_{proj} \frac{\pi r_0^2 A_T^{2/3}}{\sigma_g}$$  \hspace{1cm} 2.22

$$= Z_{proj} \frac{A_T^{2/3}}{\left(A_p^{1/3} + A_T^{1/3}\right)^2}$$  \hspace{1cm} 2.23

Similarly, the average number of participants from the target nucleus is

$$\left\langle Z_{\text{part}}^{\text{tar}} \right\rangle = Z_{tar} \frac{A_P^{2/3}}{\left(A_p^{1/3} + A_T^{1/3}\right)^2}$$  \hspace{1cm} 2.24

where $Z_{tar}$ represents number of protons in the target nucleus.

Thus the total number of participant protons $Z_{eff}^{\text{part}}$ is given by

$$Z_{eff}^{\text{part}} = \left\langle Z_{\text{part}}^{\text{proj}} \right\rangle + \left\langle Z_{\text{part}}^{\text{tar}} \right\rangle$$  \hspace{1cm} 2.25

$$= \frac{Z_{proj} A_T^{2/3} + Z_{tar} A_P^{2/3}}{\left(A_p^{1/3} + A_T^{1/3}\right)^2}$$  \hspace{1cm} 2.26

Similarly, the total number of protons of target and projectile spectators are respectively given as

$$Z_{eff}^{\text{proj.spectator}} = Z_{proj} \cdot \left\langle Z_{\text{part}}^{\text{proj}} \right\rangle$$  \hspace{1cm} 2.27
The merits of this model are its simplicity and non-involvement of the adjustable parameters.

2.7.2 Firestreak Model

The nuclear firestreak model was proposed by Myers [25]. It is a generalization of the fireball model. It explicitly includes chemical equilibrium among the hadronic species as well as thermal equilibrium. In this model, the overlapping volume of the colliding nuclei is divided into a series of tubes parallel to the direction of projectile beam. According to this model, each projectile tube interacts only with that target tube which lies directly in its path and forms a fire streak. Tube-tube collisions are treated as in the fireball model assuming thermalization to occur in each of the tube-tube collisions separately. At every impact parameter the energy available for thermalization in each tube individually is to be calculated. Production of protons can be described by this model.

The nuclear matter in each case can be treated as a thermodynamic system in chemical equilibrium. As a natural consequence of the fire streak geometry, there exists a temperature gradient across the fireball. Furthermore in the model, the angular momentum is conserved, whereas in the case of nuclear fireball model it is not. The energy range of this model is limited. It is not expected to work at very low energies, where the whole target and projectile may combine and subsequently decay. At extremely high energies the target may become partially transparent to the projectile due to fall of the nucleon-nucleon cross section. The only free parameter in this model is the freeze out density below which the hadrons stop interacting.
2.7.3 Hydrodynamical Model

The first hydrodynamic model for relativistic collisions was the Fermi-Landau model [26] describing $p-p$ collisions at very high energies. Later Hydrodynamical models [27-29] have been developed for nucleus-nucleus collisions also. According to these models, the target and projectile nuclei instantaneously merge just after the collision and attain equilibrium by forming a drop of nuclear fluid whose subsequent evolution in time is governed by standard laws of thermodynamics. The outward flow of fluid is primarily along the axis of the beam of nuclei and most of the particle production takes place during the initial collision when the projectile and target nuclei merge together. And after that the matter may undergo hydrodynamical expansion. The two nuclear fluids, projectile fluid and target fluid are considered in these models. The behaviour of each of these fluids is determined by the fluid dynamics, conservation equation for nucleon number, momentum and energy. Additional terms are introduced into these equations to allow for a coupling of two fluids by means of energy and momentum transfer. There are some constraints for the validity of fluid dynamics. They are: (i) the system comprising of the two colliding nuclei must contain a large number of degrees of freedom, (ii) the collision must last a sufficiently long time for local equilibrium to occur and (iii) either the bombarding energy must low or the interaction strength between the two nuclei must be large. Constraint (iii) ensures that the two nuclei merge instantaneously to form a single fluid.

2.7.4 Wounded Nucleon Model

Wounded nucleon model is the simplest and historically the first predictor of multiparticle production in nucleus-nucleus collisions. If $n_{AA}$ represents particle multiplicity in nucleus-nucleus collisions at a given energy then according to this model

$$n_{AA} = \frac{1}{2} W \times n_{pp},$$

where $W$ is the average number of participating or wounded nucleons and $n_{pp}$ represents the average proton multiplicity at an equivalent energy per nucleon. The number of wounded nucleons contains all the geometrical effects, i.e. the effects of nuclear radii, density and impact parameter and it can be given in terms of interaction cross sections $\sigma$ [30,31] as
\[ W = A_T \frac{\sigma_{NP}}{\sigma_{PT}} + A_p \frac{\sigma_{NT}}{\sigma_{PT}}, \tag{2.32} \]

\[ = W_T + W_P \tag{2.33} \]

where subscript \( P \) and \( T \) denote projectile and target respectively, \( N \) denotes an individual nucleon. \( \sigma_{PT} \) is the total inelastic hadronic cross-section for the projectile nucleus interacting with the target [32], and \( \sigma_{NP} \) and \( \sigma_{NT} \) are the corresponding nucleon-nucleus cross-sections. \( A_p \) and \( A_T \) denote the mass numbers of projectile and target nuclei respectively. In Equation 2.33 the terms \( W_T \) represents the number of wounded target nucleons where

\[ W_T = A_T \frac{\sigma_{NP}}{\sigma_{PT}} \tag{2.34} \]

and \( W_P \) represents the number of wounded projectile nucleons where

\[ W_P = A_p \frac{\sigma_{NT}}{\sigma_{PT}} \tag{2.35} \]

In the central nucleus-nucleus collisions, the number of total wounded nucleons \( W \), which depends on the cross sections that are functions of the maximum impact parameter \( b_{\text{max}} \), is determined with the help of the maximum impact parameter. The value of \( b_{\text{max}} \) for the central nucleus-nucleus collisions can be determined from the partial cross section as given by

\[ \sigma_{\text{par}} = \pi b_{\text{max}}^2 = \sigma_{PT} \frac{N_{\text{central}}}{N_{\text{total}}}, \tag{2.36} \]

where \( N_{\text{central}} \) is the number of central collisions in the data sample and \( N_{\text{total}} \) is the total number of nucleus-nucleus collisions obtained from a minimum bias scan of emulsions. The wounded nucleon model predicts that the cross-section for the excited nucleons due to various interactions is assumed to be the same as that for the unexcited nucleons. Using above assumptions, the number of target and projectile collisions may be obtained by the relations

\[ \nu_T = A_T \frac{\sigma_{NN}}{\sigma_{NT}} \tag{2.37} \]
and

\[ \nu_p = A_p \frac{\sigma_{NN}}{\sigma_{NP}} \]

where \( \nu_T \) and \( \nu_p \) denote the average number of target and projectile collisions respectively, \( \sigma_{NN} \) is the nucleon-nucleon production cross section. Further the total number of collisions caused by the projectile nucleons with the target nucleons may be obtained from the relation

\[ \nu = W_p \nu_T = W_T \nu_p \]

It has been reported [31-33] that the predictions of the wounded nucleon model are quite compatible with results obtained for experimental as well as FRITIOF data at SPS energies.

2.7.5 Inside-Outside Cascade Model

During a head on collision of two equal nuclei in the center of mass frame, a substantial Lorentz contraction occurs in the longitudinal direction. We can represent the two colliding nuclei by two thin disks. For simplicity, consider the collision at extremely high energy so that the longitudinal thickness of the nuclei can be neglected and the longitudinal coordinates of the nucleon of the same nucleus can be approximated to be the same.

Figure 2.1 shows the configuration of the two nuclei before collision in the center of mass system. The projectile nucleus P comes from \( Z=-\infty \) with a velocity close to the speed of light and meets the target nucleus T which comes from \( Z=+\infty \) also with the speed close to the speed of light. They meet at \( Z=0 \) and \( t=0 \), where collisions of the nucleons of the projectile nucleus with the nucleons of the target nucleus take place. Then at some later time, \( t \), the system can be seen as composed of separate projectile and target remnant regions, with a cylinder of hot material stretching between them. We can imagine a thin slice of this stretching cylinder, chosen so that the material within the slice is all moving at approximately the same velocity along the beam axis. In this model, Bjorken [34] assumed that shortly after the collision equal amounts of energy are deposited in each of these frames. This initial condition allows the evolution of the system to be described by simple hydrodynamic equations. With these assumptions he showed that the entropy \( S \) remains constant per unit rapidity, preserving a record of the early conditions in the collision [34,35].
Figure 2.1: (a) The configuration of two colliding nuclei P and T before collision. (b) The configuration after collision with energy deposited in the region around Z ~ 0.
2.8 Event Generators

2.8.1 FRITIOF

To observe the signals from $QGP$ we need non-$QGP$ background. For this purpose some event generators are built according to non-$QGP$ models based on known physics. FRITIOF is such a non-$QGP$ model, which has succeeded in describing many experimental data on hadron-hadron collisions from low energies at ISR up to top of SPS energy [36] by careful treatment of gluon radiation and hard parton scattering. In this model, during the collision, two hadrons are excited due to momentum transfer and the highly excited string like objects (colour dipole) are allowed to emit gluons until transverse momentum of emission of gluon reaches a given minimal cut. Then the formed objects are fragmented into final hadrons. The FRITIOF model has also been developed to describe hadron-nucleus and nucleus-nucleus collisions by assuming that the reaction is a superposition of hadron-hadron collisions in which geometry of nucleus plays an important role. This picture is based on the fact that the global features in nucleus-nucleus collisions are satisfactorily explained by the collision geometry together with independent hadron-hadron collisions.

2.8.2 UrQMD

The Ultrarelativistic Quantum Molecular Dynamics (UrQMD) model is based on transport theory, which played an important role in the interpretation of experimental results and in predicting new interesting effects in relativistic nucleus-nucleus collisions. The UrQMD model is the first microscopic model, which attempts to include the colour coherent phenomena [37,38]. It is based on a colour string formation and resonance decay. It is designed to study multifragmentation, correlations, rapidity distributions etc. It can be used to simulate the data for nucleus-nucleus collisions in the energy range from SIS (Schwer Ionen Synchrotron) to RHIC (Relativistic Heavy Ion Collider). It runs on various UNIX based computing platforms. The program is written in FORTRAN.
References