Role of Active Gluons in Hadron Interactions at High Multiplicity

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Abstract

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Multiparticle processes are becoming increasingly important in understanding the behaviour of fundamental particles and towards completing a grand unified theory which is the unification of the four fundamental forces of nature. In this paper we will be discussing only electron positron annihilation and proton-antiproton pair annihilation processes with more emphasis on the latter. The physics behind the complex theories involve heavy mathematics and a thorough understanding of particle physics , most importantly group theory and gauge theories with local symmetries. Gluons are fundamental particles that are the mediators of strong force. In order to comprehend the particles emitted, their multiplicity distributions have been studied experimentally as well as theoretically using quantum chromodynamics. To explain the same different models have been developed, the two stage model being the most accepted. Methods of detection of particles using the facilities available at JINR have been discussed in a separate chapter. The data analysis of the experimental results have been done using the CERN Root Software.

Acknowledgements

I am immensely grateful to JINR, Russia forgiving me this golden opportunity to work at this prestigious institute. I am indeed honoured to have Dr. Elena Kokoulina as my mentor and her unwavering support has made the completion of this project possible. I would also like to thank my team partner Miss Yara Shousha of Alexandria University, Egypt for her support. By doing this project, I have embarked on a remarkable journey to learning in depth about particle physics and developed a special interest and a knack for this field. From learning Feynman diagrams to doing complex calculations, it has been an enriching experience altogether.

Contents

Chapter 1

Basics of multiplicity distribution Part I

1.1 Multiplicity:

Multiplicity is the number of charged particles produced during collisions of particles and other high-energy reactions.

1.2 Multiplicity Distribution:

Multiplicity Distribution for a multiparticle reaction is defined as the probability of obtaining a definite number of particles produced from collision.

In the reaction:

$$p + p \rightarrow n\pi + 2N$$

, the scaling factor is defined as $z = \frac{n}{\bar{n}}$.

At very high multiplicity and near the reaction threshold, all particles have a small number of relative momentum which equivalent to a system in quark-gluon plasma.

1.3 Some important functions to describe multiplicity

1.3.1 Negative Binomial Distribution

It is also called Polya. It is denoted by K_p.

$$K_p = \frac{\tilde{A}}{A} \tag{1.1}$$

Now, we define the multiplicity distribution of gluons, denoted by P_m.

$$P_m = \frac{K_p(K_p+1)...(K_p+m-1)}{m!}(\frac{K_p}{K_p+m})^{K_p}(\frac{\bar{m}}{\bar{m}+K_p})^m \tag{1.2}$$

where m is the multiplicity of the gluon and $\bar{m}$ is the mean multiplicity.

1.3.2 Farry Distribution of gluon jets

The generation function is given by G(z) and is represented by:

$$G(z) = \sum_{m=0}^{\infty} P_m z^m \tag{1.3}$$

$$\bar{m} = \sum_{m=0}^{\infty} m P_m \tag{1.4}$$

Now we express $\bar{m}$ in terms of the generation function. To do this, we take the partial differentiation of G. Hence,

$$\frac{\partial G}{\partial z} = \sum_{m=0}^{\infty} m z^{m-1} P_m$$

$$\Rightarrow \frac{\partial G}{\partial z}\Big|_{z=1} = \sum_{m=0}^{\infty} m P_m = \bar{m}$$

1.3.3 Second Correlated Moment

The second correlated moment is found by doubly differentiating the generation function. It is denoted by f_2.

$$f_2 = \overline{m(m-1)} - (\bar{m})^2 \tag{1.5}$$

Now,

$$m(\bar{m}-1) = \frac{\partial^2 G}{\partial z^2}\Big|_{z=1}$$

$$\Rightarrow m(\bar{m}-1) = \sum_{m=0}^{\infty} m(m-1)z^{m-2}P_m\Big|_{z=1}$$

$$\Rightarrow P_m = \frac{1}{m!}\frac{\partial^m G}{\partial u_g^m}\Big|_{u_g=0}$$

Now,

$$G(z) = P_0 + zP_1 + z^2P_2 + ...$$

$$G(z)\Big|_{z=0} = P_0$$

$$\frac{\partial G}{\partial z} = P_1 + 2zP_2 + 3z^2P_2 + ... + nP_nz^{n-1}$$

$$\Rightarrow \frac{\partial G}{\partial z}\Big|_{z=0} = P_1$$

$$\Rightarrow \frac{\partial^2 G}{\partial z^2} = 2P_2 + 3.2zP_3 + ... + n(n-1)z^{n-2}P_n$$

$$\Rightarrow P_m = \frac{\partial^2 G}{\partial z^2}\Big|_{z=0} = 1.2.3P_3$$

$$\Rightarrow n!P_n = \frac{\partial^n G}{\partial z^n}\Big|_{z=0}$$

$$\Rightarrow P_n = \frac{1}{n!}\frac{\partial^n G}{\partial z^n}\Big|_{z=0}$$

Chapter 2

Basics of multiplicity distribution Part II

2.1 More on distribution and generation functions

From the previous chapter we have seen that:

$$Q(z) = \sum P_n z^n$$

And

$$\bar{n} = \frac{\partial Q}{\partial z}|_{z=1}$$

$$D_2 = \frac{\partial^Q}{\partial z^2}|_{z=1} - (\frac{\partial Q}{\partial z})^2|_{z=1} + \frac{\partial Q}{\partial z}|_{z=1}$$

$$\frac{\partial^2 Q}{\partial z^2} = \sum n(n-1) z^{n-2} P_n|_{z=1} = \overline{n(n-1)}$$

$$D_2 = \bar{n^2} - \bar{n}^2 = \overline{n(n-1)} - \bar{n}^2 + \bar{n}$$

$$D_2 = f_2 + \bar{n}$$

which include Poisson Distribution.

Among the models that have been proposed until now for pp interactions, we consider the two component model. Here, the diffraction dissociation expected is energy independent and they populate low multiplicity channels. While, the non diffractive production is responsible for explaining observations that logarithmically increase in average multiplicity and its multiplicity distribution has been explained in terms of Poisson distribution.

2.2 What are active gluons?

We know that in inelastic collisions, the particles before and after the reaction are not the same and the momentum varies as well. When an inelastic collision between two protons occur, a part of the energy is converted into thermal energy. Then, the proton constituents, viz., the quarks and the gluons can be explained by perturbative quantum chromodynamics as the strong coupling between the gluons approach a small value and the gluons become asymptotically free.

To study their behaviour, we take the help of two models.

- Branch model- When we are interested in what is happening in the QGS(Quark Gluon System).
- Thermodynamic model- When we are not interested in what is happening in the QGS.

Some gluons leave the QGS and convert to real hadrons or hadron resonances in the course of time. Such gluons are termed as **active gluons**.

Chapter 3

Physics of electron positron annihilation

3.1 Introduction

Physicists always focus on accelerating of stable particles. Some of the reactions in which multiparticle production occurs are: electron-positron annihilation, proton-proton inelastic scattering, proton-antiproton annihilation, three-gluon decay quarkoniums, lepton-hadron interactions and last but not the least, collisions of high energy ions. As a matter of fact, in Fermilab, the experiment of making 900GeV protons collide into 900 GeV antiprotons confirmed the presence of top quarks.

Importance of topological cross section

A topological cross section σ_n is the cross section of creation of n charged particles at the interaction of two initial particles. Total inelastic cross section is the sum of all topological cross sections: $\sigma_{inel} = \Sigma_n \sigma_n$. The ratio of the topological cross section to inelastic cross section determines the probability of formation of n secondary particles $P_n = \sigma_n / \sigma_{inel}$.

In according to QCD the main language for description of interaction is based on quarks and gluons. How to make transit to the real observable hadrons? This theory of strong interaction (QCD) doesn't give us answer. The importance of the cross section measurement is that it gives us a tool to check the correctness of the Standard Model with addition of hadronization described by phenomenological way. Then we can compare experimental data to theoretical predictions.

3.2 Two stage model (TSM)

To explain the multiparticle production, a Gluon Dominance Model(GDM) has been developed, which is a convolution of two stages. The first stage is a part of QCD while the second stage, which is the hadronization stage, a phenomenological model is used. The simplest case of study combination of QCD and phenomenological scheme of hadronization is electron-positron annihilation. It will be taken into consideration in this report. It accounts for the quark-gluon cascade, causing quarks to emit gluons, gluons can give fission and eventually all quarks and gluons must turn into hadrons at the hadronization stage.

Analysing it theoretically as well as using the data available, it has been shown that explaining of the quark gluon cascade is easier with the dominance of bremsstrahlung gluons. The valence quarks stay in the leading particles and are passive, while the gluons are single-handedly responsible for the high multiplicity of the process.
In according to QCD the probabilities of three elementary processes are:

$$P(q \to qg) = C_F \frac{1+z^2}{1-z},$$

$$P(g \to gg) = 2C_A \frac{[1 - z((1-z)^2)]}{z(1-z)},$$

$$P(g \to q\bar{q}) = T_F[z^2 + (1-z)^2],$$

And integrals from them are:

$$A = \int_{\epsilon'}^{1-\epsilon'} P(g \to gg)\, dz = \frac{C_A}{\epsilon}$$

$$\tilde{A} = \int_{\epsilon'}^{1-\epsilon'} P(q \to qg)\, dz = \frac{C_F}{\epsilon},$$

$$B = \int_{\epsilon'}^{1-\epsilon'} P(g \to q\bar{q}) dz = \frac{2T_F}{3}$$

$$\epsilon = (-2ln\epsilon')^{-}1$$

where z is the parton momentum fraction and ϵ' is the cut-off parameter

It's comfortable to use the generation function Q(s,z) $= \Sigma_{n=0}^{\infty} P_n z^n$. The multiplicity distributions are calculated as follows:

$$P_n(s) = \frac{1}{n!} \frac{\partial^n}{\partial z^n} Q(s.z)|_{z=0}$$

.
The factorial moments are calculated as:

$$F_k(s) = \overline{n(n-1)....(n-k+1)} = \frac{\partial^k}{\partial z^k} Q(s,z)|_{z=1},$$

k=1, 2, ...
The variance of the distribution is:

$$D = \sigma^2 = \overline{n(n-1)} - \overline{n}^2 + \overline{n}$$

$$= F_2 - \overline{n}^2 + \overline{n}$$

$$= f_2 + \overline{n},$$

where $f_2 = F_2 - F_1^2$ is the second correlative moment, $F_1 = \overline{n}$ is the average multiplicity.

From Giovannini's work, [**Giovannini**] we find that the Markov nature of elementary processes such as gluon fission, quark pair-creation from gluon, quark bremsstrahlung at the first order of α_s lead to the description of various QCD jets (quark and gluon). The stochastic approach plays an important role in finding the multiplicity distribution of parton jets as a function of their thickness and elementary processes of cross sections.

The natural QCD parameter is:

$$Y = \frac{1}{2\pi b} log[1 + \alpha b log \frac{Q^2}{\mu^2}],$$

$Y = 0$ at $Q = \mu$ the first stage can start. We call Y the thickness value of a quark or a gluon which gives origin to a quark or a gluon jet.Three main elementary processes contribute with different weights to the overall quark or gluon distributions inside QCD jets:

(i) gluon fission: $g \to g + g$,
(ii) quark bremsstrahlung: $q \to q + g$,
(iii) quark pair creation: $g \to q + \bar{q}$.

The probability generating functions for a gluon jet and a quark jet will be respectively:

$$G(u_g, u_q; Y) = \sum_{n_g, n_q = 0}^{\infty} P_{1,0;n_g,n_q}(Y) u_g^{n_g} u_q^{n_q}$$

$$Q(u_g, u_q; Y) = \sum_{n_g, n_q = 0}^{\infty} P_{0,1;n_g,n_q}(Y) u_g^{n_g} u_q^{n_q}.$$

P_{m_g,m_q,n_g,n_q} represents the probability of m_g gluons and m_q quarks being transformed into n_g gluons and n_q quarks over a jet of thickness Y.From a probabilistic point of view the total parton population (m_g gluons and m_q quarks) evolving through thickness Y behaves as (m_g + m_q) independent parton populations, each with one initial quark or gluon; this fact summarizes the branching Markov chain nature of the process.

3.3 Three-gluon decay of bottomium

We can apply this approach to the three-gluon decay of upsilon meson (bottommium). For this purpose it's necessary to define for three-gluon state by using a single gluon jet.

The generation function for a single gluon is given by:

$$Q(s,z) = \frac{z}{\overline{m}/3}[1 - z(1 - \frac{1}{\overline{m}/3})]^{-1}$$

$$Q^{(3g)} = [Q^{(g)}]^3 = (\frac{z}{\overline{m}/3}[1 - z(1 - \frac{1}{\overline{m}/3})]^{-1})^3$$

where $\overline{m}/3$ is the average multiplicity of every gluon jet.

$$Q^{(3g)} = \frac{z^3}{(\overline{m}/3)^3}[1 - z(1 - \frac{1}{\overline{m}/3})]^{-3}$$

$$P_m = \frac{1}{m!}\frac{\partial^m}{\partial z^m}Q^{(3g)}(z)$$

So,

$$P_m = \frac{(m-1)(m-2)}{2(\overline{m}/3)^3}(1 - \frac{1}{\overline{m}/3})^{m-3}$$

According to the experimental behavior of the second correlative moment f_2 which gives the negative value we should choose for the hadronization stage multiplicity distribution with negative f_2. The most known for that distribution is the binomial one:

$$P_n = C_N^n p^n (1-p)^{N-n},$$

where n is the number of successes, N - maximum of trails. The probability of single success can be expressed as the ratio of two values: $\overline{n}^h$ and N, average number and maximum number of hadrons that can form at the second stage (hadronization).

The above equation is the expression for the binomial distribution with a second correlation moment for hadrons from the parton(quark or gluon) jet in the second stage, i.e., the hadronization stage in the Gluon Dominance Model. At energies of a few GeV when the number of partons at the stage of the qg-cascade is small, the hadronization is predominant and determines the sign of the second correlative moment that is negative.

The g-stage and hadronization is represented by:

$$Q(s,z)=\sum_{m=3}^{\infty}P_m^g[1-\frac{\overline{n}^h}{N}(1-z)]^{mN_g}$$

The multiplicity distribution function for the two gluon decay is given by:

$$f_2=\frac{\partial^2}{\partial z^2}Q(z)\mid_{z=1}-(\frac{\partial}{\partial z}Q(z))^2=n(\bar{n-1})-\bar{n}$$

Now coming to the 3-gluon decay, the multiplicity distribution of hadrons is given by the expression:

$$P_n(s)=\sum P_m C_{mN}^n(\frac{\bar{n}}{N})^n(1-\frac{\bar{n}}{N})^{mN-n}$$

$$f_2=<n(n-1)>-<n>^2=D_2-<n>=<n^2>-<n>^2-<n>$$

The gluon distribution is:

$$P_m^{(g)}=\frac{1}{(m-3)!}\frac{\partial^m-3}{\partial z^{m-3}}[1-z(1-\frac{1}{\bar{m}/3})]^-3|_{z=0}$$

$$\Rightarrow P_m^{(g)}=\frac{1}{(m-3)!}(1-\frac{1}{\bar{m}/3})^{m-3}\frac{1}{(\bar{m}/3)^3}\frac{(m-1)!}{2}$$

$$\Rightarrow P_m^{(g)}=\frac{(m-2)(m-1)}{2(\overline{m}/3)^3}(1-\frac{1}{\bar{m}/3})^{m-3}$$

And,

$$f_2=(\frac{\bar{m}^2}{3}-\frac{\bar{m}}{N_g}-\frac{3}{N_g})$$

Multiplicity distribution for the three gluon decay of bottomonium has the following view:

$$P_n(s)=\sum_{m'}\frac{(m'+1)(m'+2)}{2(\overline{m}/3)^2}(1-\frac{1}{\overline{m}/3})^{m'}C_{(3+m')N_g}^{m}(\frac{\overline{n}_g^h)}{N_g})^n(1-\frac{\overline{n}_g^h}{N_g})^{(3+m')N_g-n}$$

In figure 1 the multiplicity of distribution of charged particles is presented. Experimental data are shown by black points and the curve corresponds to model description.

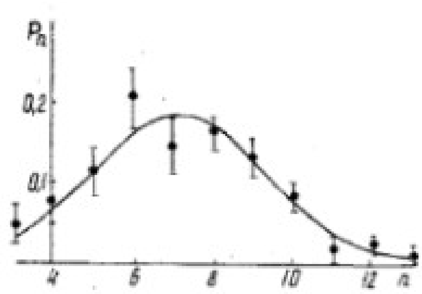

Figure 3.1: three gluon decay for bottomium

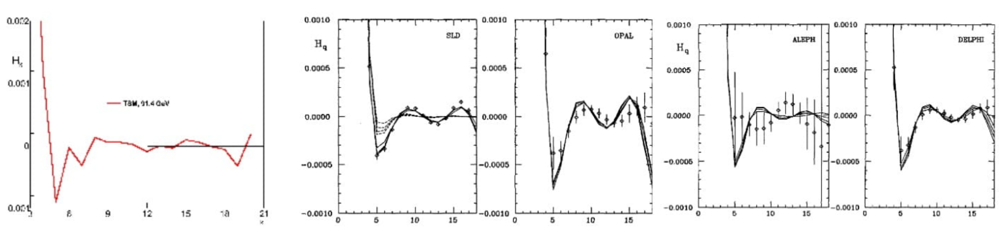

Figure 3.2: factorial, cumulative moments and their ratio

In figure 2 we show the ratio of cumulative to factorial moments calculated by two-stage model (left figure) and four figures (on the right) from data (OPAL, DELPHI, SLD, and ALEPH collaborations).

In the conclusion, we have shown that using of the convolution of two stage of multiparticle production the three-gluon decay into hadrons can be described well.

Chapter 4

Detection of pp Interaction

4.1 pp Interactions

Definition:

4.2 Experimental setup of observing pp interaction

We will focus on pp(proton-proton) interactions, the experiments of which have been carried out at the accelerator U-70 in a small town in Moscow, called Protvino. The proton beam that is used for this purpose has a beam energy of 50 GeV/c. The setup used for the same is SVD(Spectrometer with Vertex Detector). Monte Carlo Generators are used for this purpose. Now referring to the figure of the SVD, we will be describing each part and their functions one by one.[**1**]

SVD was originally constructed to study the production and decay of charm particles. Now its installation has made it possible to detect events with high multiplicity of charged particles and γ quanta.

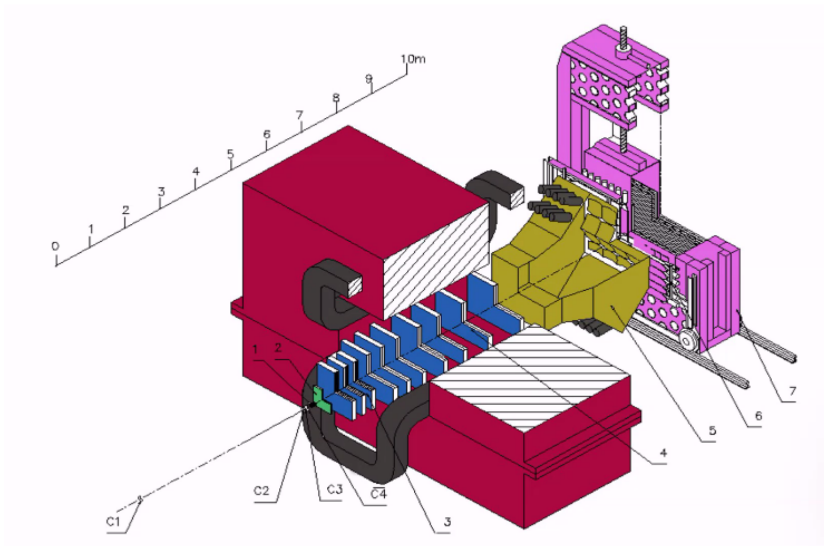

Figure 4.1: Structure of SVD

Labelling Figure 2.1	
Identification number in Fig.1	Object
C1,C2	Beam scintillation and Si-hodoscope
C3	target station
C4	vertex Si-detector
1,2,3	drift tubes track system
4	magnetic spectrometer proportional chamber
5	threshold Cherenkov counter
6	scintillation hodoscope
7	electromagnetic calorimeter

4.2.1 Beam stations

There are 6 beam stations, made up of Silicon strip detectors that are necessary to trigger the event and record them. The distance between each detector is called pitch and the pitch for the above beam station is 50 μm. Each strip has a potential of its own and they are included as a part of a bigger circle. The currents can be detected in them. As a matter of fact, the current signals come from the electrons present there.

Calculating x_2

Let the total number of strips be 640. From the figure, to calculate the distance x_2,

$$(N_{strip} - 320)d - d = x_2$$

$$\bar{X} = \frac{\sum x_i A_i}{\sum A_i} - hit$$

Finding projection equation for beam station

The vertex detector has 10 silicon plates.
X: Vertical strips, Y: Horizontal strips
$u_i(z_j)$: Argument of strip where i=number of track, u-coordinate of i^{th} track, i=1,2,3,....,N
z_j: z coordinate of j^{th} detector

Projection Equation:

$$u_i(z_j) = (x_{0i} + tx_i z_j)cos\alpha_j + (y_{0i} + ty_i z_j)sin\alpha_j$$

where

$$XOZ = X_0 + t_x Z$$

and

$$YOZ = Y_0 + t_y Z$$

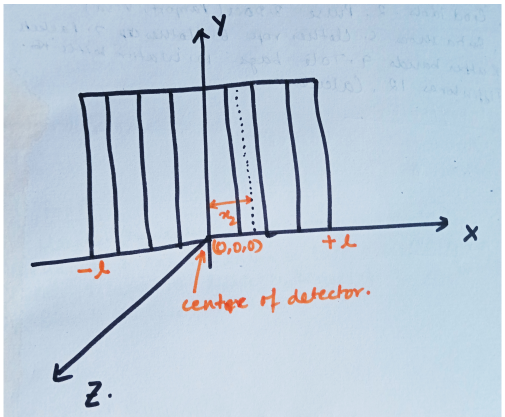

Figure 4.2: Strip Detector Schematic Diagram

4.2.2 Use of H_2(liq) for target:

The scheme of the proton bean goes as follows:
Proton beam emission → Beam station → Hydrogen target(liq hydrogen) → Vertex detectors → gas detectors → Proportional Chambers → Electromagnetic Calorimeters

Once the beam reaches the High Multiplicity Trigger(HMT), the protons interact with this trigger and helps to exclude events of low multiplicity(n=8).
If d is the pitch and σ is the dispersion or variance, then,

$$\sigma^2 = d\int_0^1 (x-\frac{1}{2})^2\,dx$$
$$\Rightarrow \sigma^2 = d\int_0^1 (x-\frac{1}{2})^2\,d(x-\frac{1}{2})$$
$$\Rightarrow \sigma^2 = \frac{d}{\sqrt{12}}$$

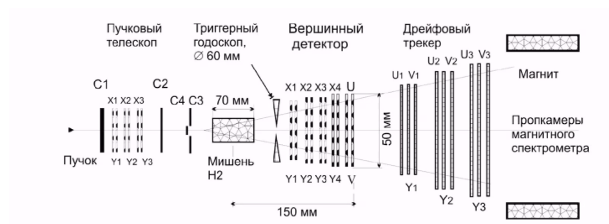

Figure 4.3: Three gluon decay for bottomium

4.2.3 Gas Detectors:

There are three modules of gas detectors with 2 layers of tubes each having a pitch of 6mm. It is filled with 70% Argon and 30% CO_2 to restrict cascading events. There is an anode wire present in it with a diameter having 5 microns and the registered time of drift is measured in nanoseconds. The Time Digital Converter has an order of 2^n. It is made sure that the background is excluded and that it works in the given interval. Hence, the calibration function is used for this purpose.

4.2.4 Proportional Chambers and Cherenkov Counter:

Each charged particle passes through the proportional chambers.
The threshold Cherenkov counter has 32 channels of signal registration from

the photomultiplier (PMT). PMTs are supplied with active magnetic field protection. The efficiency of generation of pions in the momentum interval 3-30 GeV is 70%. It is connected to insufficient magnetic field compensation and a possible leak of air in a radiator filled with freons. The γd detector consists of 1536 full absorption Cherenkov counters. Radiators from a lead glass have the size $38 \times 38 \times 505$ $mm^3$3 and are connected with PMT-84-3. The total fiducial area of the detector is 1.8×1.2 m^2. The energy resolution of 15 GeV electrons is 12 %. The accuracy of the γ quantum coordinate reconstruction is approximately 2 mm.

Chapter 5

Physics of pp interaction

5.1 Outline of pp interaction

The proton-proton interaction results in particles with high multiplicity, where $n >> \bar{n}$. It is a collective phenomena in the high multiplicity region. Particles like π^+, π^0 and π^- are produced.
The two main features that we have to keep in mind while discussing about pp interactions are:

- Every quark can develop branching narrow binomial distribution.

- Every gluon can develop Farry Distribution.

$$Q = [1 + \frac{\bar{m}}{\mu}(1-z)^{-\mu}]^6 [G(z)]^{n_g} \tag{5.1}$$

Only gluons can take part in the multiparticle processes while quarks stay as spectators.
Now, we will see two important examples of pp reactions:

$$p + p \to \pi^+ + n + p$$
$$p + p \to \pi^0 + p \to \pi^+ + n + p$$

For quarks and gluons, the multiplicity distribution can be written as:

$$P_m = \frac{\bar{m}e^{-m}}{m!} \tag{5.2}$$

The equation for the simple scheme is:

$$Q(z) = \sum \frac{\bar{m}e^{-m}}{m!}[1 + \frac{\bar{n}}{N}(z-1)]^{mN}$$

where $\bar{n}^h$ is the average multiplicity of hadrons which form single gluon and N is the maximum number of hadrons that can be created from a single gluon.

The content of weak gluons is just 50 percent of the total number formed. They are glued to valence quarks of secondary particles and give them mass. We see that:

$$q + g \rightarrow q + \gamma \rightarrow ComptonScattering$$

5.2 I-scheme with gluon fission

We shall now discuss the I-scheme of gluon fission which has three stages to it. They are:

5.2.1 Appearance of free gluons:

Its multiplicity distribution function is denoted by the expression:

$$P_m = \sum e^{-k}\frac{\bar{k}}{k!}\sum \frac{1}{\bar{m}^k}\frac{(m-1)(m-2)...(m-k)}{(k-1)!}(1 - \frac{1}{\bar{m}^{m-k}}C^{m-k}_{\alpha mN}(\frac{\bar{n}^h}{N})^{n-2}(1 - \frac{\bar{n}^h}{N})^{\alpha mN-(n-2)}$$

Now,

$$\sum e^{-k}\frac{\bar{k}}{k!}$$

corresponds to the Poisson Distribution.

$$\sum \frac{1}{\bar{m}^k}\frac{(m-1)(m-2)...(m-k)}{(k-1)!}(1 - \frac{1}{\bar{m}^{m-k}}$$

corresponds to the Farry Distribution of the gluon get.
Lastly,

$$C^{m-k}_{\alpha mN}(\frac{\bar{n}^h}{N})^{n-2}(1 - \frac{\bar{n}^h}{N})^{\alpha mN-(n-2)}$$

corresponds to the Binomial Distribution of the hadronization stage.

If k=0, then this expression should be explicit as the equation shows that the basic sources of secondary particles are active gluons and not valent quarks, where $\bar{k}$ is the average number of gluons at the moment of collision and $\bar{m}$ is the average number of gluons after fission. Among all the events, we deal with events with maximum number of hadrons which is N. The number of gluon fission is huge but the number of hadrons is constrained. Not all gluons give hadrons , some of them stay in the quark-gluon systems. Sources of soft photons give mostly secondary particles. two protons are leading particles. they are conserved and do not disappear. In the expression $C_{\alpha mN}^{n-2}$, αm is the real number of gluons that give hadrons.

5.2.2 Formation of fission gluon:

The Farry distribution is used to know how many gluons don;t take part in gluon fission. We are interested in gluons produced after fission. According to the data obtained from the experiments, $\bar{u} = 2.5$, $\bar{m} = 2.6$, $\bar{n} = 2.5$,, N=40, $\sqrt{s} = 10$GeV.
By analysing the data we can find out that high multiplicity events are extremely rare , with small probabilities.

The presence of several gluons allows to give a lot of quark-antiquark pairs which form hadrons and in this quark-gluon system, the formation of baryons or mesons is released with the same probability and its ratio increases as energy tends to 1.

5.2.3 Hadronization

The last and final stage is the hadronization process. It can be measured and analysed accurately with the help of different hadronization parameters.

Chapter 6

Intermediate Quark Charge Topology

6.1 Topological Charge

Topological charge is an important parameter in dealing with multiparticle processes. It is defined as the ratio of the number of baryons and the number of fermions generated. If this ratio is dependent on the baryonic matter, then the conservation of baryons will be dependent upon the conservation of charges on quarks.

For the proton proton annihilation, it is represented by the expression:

$$P_n = C_0 \sum_{m_1} \frac{\bar{m_1}^{m_1} e^{-\bar{m}_1}}{m_1!} C^n_{m_1 N} (\frac{\bar{n}^h}{N})(1-\frac{\bar{n}^h}{N})^{mN-n} + C_2 \sum_{m_2} \frac{\bar{m_2}^{m_2} e^{-\bar{m}_2}}{m_2!} C^{n-2}_{m_2 N} (\frac{\bar{n}^h}{N})(1-\frac{\bar{n}^h}{N})^{mN-(n-2)}$$

$$+C_4 \sum_{m_3} \frac{\bar{m_3}^{m_3} e^{-\bar{m}_3}}{m_3!} C^n_{m_3 N} (\frac{\bar{n}^h}{N})(1-\frac{\bar{n}^h}{N})^{mN-(n-4)}$$

It has been usually seen that the ratio of C_0, C_2 and C_4 is 15:40:0.05. Three quark pairs are formed ($q\bar{q}$ and every pair gives us hadrons. So the second correlative moment continues to be negative for proton-antiproton. The total energy is $\frac{\sqrt{s}}{3}$ and hadronization is the predominant stage.

The formation of π^0 mesons is easier than the formation of baryons. Quarks are coloured and hadrons do not have colour associated with them

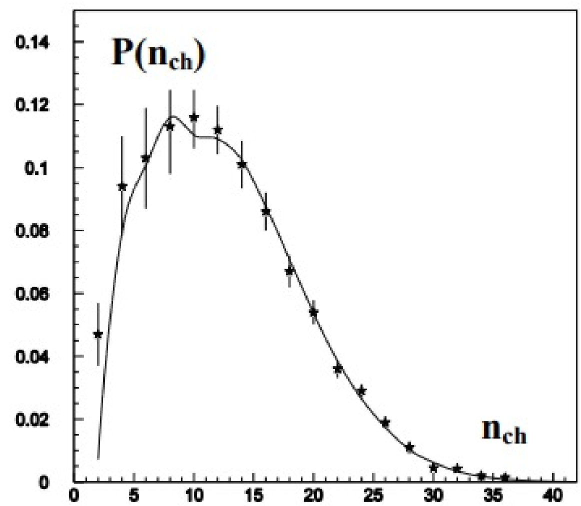

Figure 6.1: At 60 GeV/c

and how the discolouration process occurs can determine meson formation of baryon pairs.

For two quark systems,

$$u_c\bar{u}_c(c = 0)$$

For three quark systems,

$$u_{c_1}d_{c_2}s_{c_3}(c_1 + c_2 + c_3 = 0)$$

$$P_m = \Omega\sum_{m=1}^{M_g}\frac{\bar{m}^m e^{-\bar{m}}}{m!}C_{mN}^{n-2}(\frac{\bar{n}^h}{N})(1-\frac{\bar{n}^h}{N})^{mN-(n-2)}$$

Two initial protons are taken. 50% re-exchange of charge occurs.

$$pp \to \pi^0 pp + \pi^+ nn$$

They are detected using calorimeters.
Particles hit calorimeters and branching is observed. The deposition of energy is in electromagnetic calorimeters for photons or neutron show different results. For neutrons, it is a very small region, for photon, the figure is white.

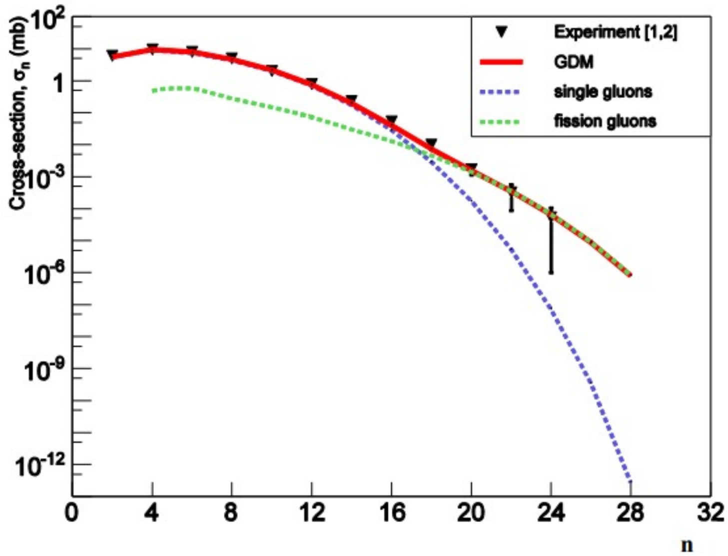

Figure 6.2: High multiplicity responsible for gluon fission

We can write the expression for the probability of the occurrence of such events in terms of the topological cross sections as:

$$P_n = \frac{\sigma_n}{\sigma_{in}}$$

Now,

$$\sum \sigma_n = \sigma_i n$$
$$log P_n = log \sigma_n + log \sigma_i n$$
$$\frac{\Delta P_n}{P_n} = \frac{\Delta \sigma_n}{\sigma_n} + \frac{\Delta \sigma_i n}{\sigma_i n}$$

$\bar{n}^h$ is the average multiplicity of hadrons that form from single gluons at hadronization stage. For electron positron annihilation, this value approximately tends to 1.

6.2 Types of Intermediate charge topology:

There are three kinds of intermediate charged topology, viz:

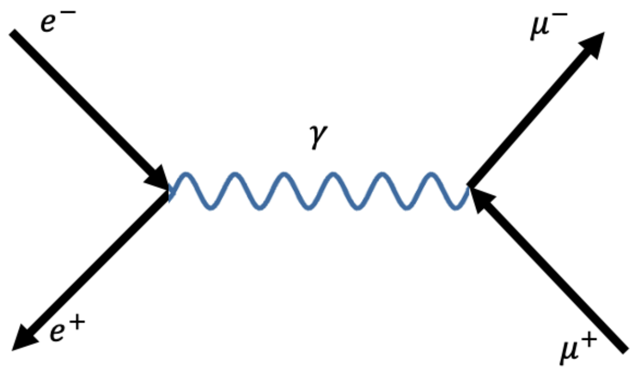

Figure 6.3: Feynman Diagram of electron positron annihilation

- "0" Topology: The particles formed are $3\pi^0$+hadrons. Quark content: (u$\bar{u}$, u$\bar{u}$, d$\bar{d}$)
- "2" Topology: Pions are formed as a result of the processes. Quark content: (u$\bar{d}$, $\bar{u}$d, u$\bar{u}$)

$$\pi^0 = \frac{u\bar{u} + d\bar{d}}{\sqrt{2}}$$

- "4" Topology: Formed from valence quarks.

6.3 Expression formulating ICT:

The expression for the multiplicity distribution is:

$$P_n(s) = C_0 \sum_{m=0}^{\infty} \frac{e^{\bar{m}}\bar{m}^m}{m!} C^n_{mN} (\frac{\bar{n}^h}{N})^n (1 - \frac{\bar{n}}{N})^{mN-n}$$

$$+C_2 \sum_{m=0}^{\infty} \frac{e^{\bar{m}}\bar{m}^m}{m!} C^{n-2}_{mN} (\frac{\bar{n}^h}{N})^{n-2} (1 - \frac{\bar{n}}{N})^{mN-(n-2)}$$

$$+C_4 \sum_{m=0}^{\infty} \frac{e^{\bar{m}}\bar{m}^m}{m!} C^{n-4}_{mN} (\frac{\bar{n}^h}{N})^{n-4} (1 - \frac{\bar{n}}{N})^{mN-(n-4)}$$

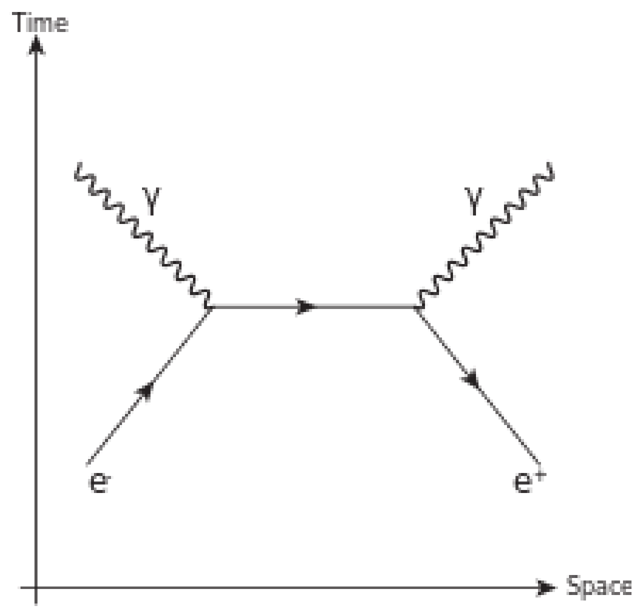

Figure 6.4: Feynman Diagram of proton antiproton annihilation

The Feynman diagrams of the electron positron and proton proton annihilation are shown. The products formed can be seen from these. Bernd Muller called the mechanism of hadronization in hadron(ion) interactions recombination mechanism in comparison to fragmentation in electron positron annihilation, which is similar to recombination in the quark-gluon medium.

The hadronization parameter $\bar{n}^h$, i.e. the average multiplicity that forms from a single gluon at hadronization stage grows with energy in proton antiproton annihilation.

$$\bar{n}(s) \sim log(\frac{\sqrt{s}}{\mu})$$

Chapter 7

Conclusion

The two stage Gluon model, the GDM(Gluon dominance Model) and consequently Giovannini's work have been described in details. The generation functions and the multiplicity distributions for electron positron annihilation and the proton-antiproton pair annihilation have been calculated and the contributions of the Binomial distribution, Poisson distribution and Farry's distribution have been analysed.

We have also obtained the second correlated moment from the generation function for electron-positron annihilation.The physics of pp interactions, detection and the intermediate charge topology associated with it have also been thoroughly discussed. The paper contains elaborate derivations of advanced topics like three gluon decay of bottomium and the simulation of theoretical with experimental values of hadronization parameters associated with multiplicity distribution using the CERN Root Software.

Chapter 8

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