JOINT INSTITUTE FOR NUCLEAR RESEARCH

Veksler and Baldin laboratory of High Energy Physics

FINAL REPORT ON THE INTEREST PROGRAMME

Active role of gluons in hadron interactions at high multiplicity (part II)

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Participation period:

Feb 26 – April 14, Wave 10

Abstract

The multiplicity distribution -number of secondaries- of charged particles produced from pp-interactions is studied at energies of 100, 102, 205, 300, 405 and 800 GeV. We did our study using Markov branching idea to fit them with the experimental data obtained. The fitting is done using a CERN's ROOT minimization library. Irregularities in the fitting parameters are found.

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1 Introduction

Valence quarks (or constituent quarks) are quarks that determine the most important properties of a hadron such as mass, momentum, electric charge and spin. For the proton, these are one down quark and two up quarks. These quarks hold the quantum numbers of this proton. However, they carry a relatively small fraction of its total mass. And as a result, the proton has a large mass of about 1000 MeV/c^2 compared to the mass of its quarks which takes a maximum of 5-7 MeV/c^2 each.

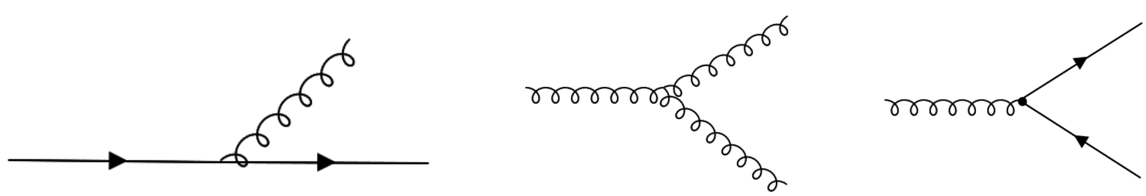
Therefore, in the system of a proton, there must be several gluons that contribute to the proton's mass. These gluons can undergo branching or fission processes. And if we have a proton-proton collision, i.e. 6 quarks and m gluons, it means that we have a very complicated interaction, much more complicated than that of e^+e^- collision.

1.1 Branching Cases

The partons (quarks and gluons) can undergo fragmentation using one of the following ways:

1. $q \to q + g$ (Quark Bremsstrahlung)
2. $g \to g + g$ (Gluon Fission)
3. $g \to q + \overline{q}$ (Quark Pair Creation)

These three cases are shown in Figure 1. We use statistical techniques to study the branching processes of partons, because the number of particles in these processes is usually greater than 60.



(a) Quark Bremsstrahlung (b) Gluon Fission (c) Quark Pair Creation

Figure 1: Partons Branching Cases

Let $A\Delta Y$ be the probability that a gluon in the infinitesimal interval ΔY will convert into two gluons, $\widetilde{A}\Delta Y$ be the probability that a quark will radiate a gluon, the quark continuing on its way, and $B\Delta Y$ be the probability that a quark-antiquark pair will be created from a gluon. A, $\widetilde{A}$, B are Y-independent constants and each individual parton acts independently from others, always with the same infinitesimal probability.

Giovannini proposed to interpret the natural QCD evolution parameter Y:

$$Y = \frac{1}{2\pi b} ln[1 + \alpha_s b ln(\frac{Q^2}{\mu^2})]$$

where $2\pi b = \frac{1}{6}(11N_C - 2N_f)$ for a theory with N_C colours and N_f flavours, as the thickness of the jets and their development as Markov process.

1.2 Markov Processes

In the probability theorem, we can calculate the probability of success k-times for an event:

$$P(k) = C_n^k p^k (1-p)^{n-k} \tag{1}$$

where k is the number of success times and n is the total number of trials.

Now, we can use the idea of Giovannini to describe the quark-gluon jets by Markov branching processes. Markov processes can be used when the probability of the process happening is only dependant on the previous process, but independent of all other previous processes.

The method of generating functions is a very important tool in the study of stochastic processes with a discrete state space.

1.3 Average Multiplicity of Gluons

The experimental results found that the leading particles are coming from the valence quarks, while secondary particles come from gluons. And it was called recombination mechanism of hadronization. This phenomenon explains the fact that the average multiplicity of hadrons created by a single gluon $\bar{n}_g^h$ must be greater than 1.

The average gluon multiplicity in the quark jet is:

$$\overline{n}_g = < n_g > = \mu(e^{AY} - 1) \tag{2}$$

At very small value of Y:

$$e^{AY} \approx 1 + AY \tag{3}$$

$$\overline{n}_g \approx \mu(1 + AY - 1)$$

$$\overline{n}_g = \mu AY = \frac{\tilde{A}}{A} AY = \tilde{A}Y \tag{4}$$

So, in this case the gluon average multiplicity only depends on $\tilde{A}$ not A because gluons radiate only via Bremsstrahlung, while gluon fission does not occur. These gluons afterwards can create quark-pair that can form mesons. It is obvious that baryons are not produced in our situation. $\frac{B}{M} << 1$. So, mesons are predominant particles. However, in experiments this value $\frac{B}{M}$ is known to increase with increasing of energy, eg: at RHIC $\frac{B}{M}$ approaches 1, and this is explained by fragmentation mechanism of hadronization.

1.4 Two Stage Model

We define this process using two stages:

1. cascade stage
2. hadronization stage

Parton spectra in QCD quark and gluon jets were studied by working at the leading logarithm approximation and avoiding IR divergences by considering finite x, the probabilistic nature of the problem has been established.

1.5 Calculations

In the Markov branching processes, we define a generating function:

$$Q = \sum_{k=0}^{\infty} P_k \, z^k \tag{5}$$

Where P_k is the probability of event success mentioned in equation 1, and z is an arbitrary factor.

Therefore, by substituting:

$$Q = \sum_{k=0}^{\infty} C_n^k p^k (1-p)^{n-k} \, z^k = \sum_{k=0}^{\infty} C_n^k (pz)^k (1-p)^{n-k} \tag{6}$$

Using Newton's binomial theorem $(a+b)^n = \sum_{k=0}^{\infty} C_n^k a^k b^{n-k}$:

$$Q = \sum_{k=0}^{\infty} C_n^k (pz)^k (1-p)^{n-k} \tag{7}$$

$$= [1 - p + pz]^n \tag{8}$$

$$Q = [1 + p(z-1)]^n \tag{9}$$

1.6 pp-interaction Calculations

We have two schemes of pp-interactions:

1.6.1 First Scheme

We have 3 pairs of quarks (u, u, u, u, d, d) + and a number of gluons m_g. We find that $\overline{n}_g^h << 1$ unlike in e^+e^- collision in which $\overline{n}_g^h = 1$. This problem in pp-interaction can be solved by excluding the effect of all valence quarks and dealing with protons as they are to eventually become leading hadrons. Meanwhile, we assume that all secondary particles are produced from what we call active gluons (gluons that can create secondary hadrons).

Our generating function of this scheme is:

$$Q(s) = \sum_{k=1,m=1}^{Mk,MG} P_k P_m [1 - \frac{\overline{n}^h}{N}(1-z)]^{mN} \tag{10}$$

P_k describes the k gluons that are available immediately after the collision. We can describe them by Poisson's distribution:

$$P_K = \frac{\overline{K}^K e^{-\overline{K}}}{K!} \tag{11}$$

Every gluon can also give m gluons by fission process using following Furry's distribution (P_{n_g}):

$$P_{n_g} = \frac{1}{(n_g - m)!} \frac{m(m+1)(m+2)...(m+n_g-1)}{\overline{m}^m} (1 - \frac{1}{\overline{m}})^{m-n_g} \tag{12}$$

Then hadronization happens.

The Multiplicity Distribution Function (P_n) is the probability of obtaining a definite number of particles produced from collisions. In order to obtain multiplicity distribution for n number of particles, we take the nth derivative of the generating function with respect to the arbitrary variable z, while substituting with z = 0, and then use the following formula:

$$P_n = \frac{1}{n!} \frac{\partial^n}{\partial z^n} Q(s,z)|_{z=0} \tag{13}$$

So, first scheme is represented by the following multiplicity distribution function:

$$P_n = \sum_{K=1}^{MK} \frac{\overline{K}^K e^{-\overline{K}}}{K!} \sum_{m=1}^{MG} \frac{1}{\overline{m}^K} \frac{(m-1)(m-2)...(m-K)}{(K-1)!} (1 - \frac{1}{\overline{m}})^{m-K} C_{\delta_{mN}}^{n-2} (\frac{\overline{n}^h}{N})^{n-2} \times (1 - \frac{\overline{n}^h}{N})^{\delta mN-(n-2)} \tag{14}$$

Note that: (n-2) is the number of newly-produced hadrons, because we have 2 protons that already existed.

1.6.2 Second Scheme

In systems of high multiplicity, these hadrons become homogeneous with the leading hadrons.

In this scheme, immediately after the collision, we also have k gluons, but this time we are only interested in the hadronization process afterwards, without taking into account the fission or branching of gluons.

$$P_n = \sum_{m=1}^{M_G} \frac{\overline{m}^m e^{-\overline{m}}}{m!} C_{mN}^{n-2} (\frac{\overline{n}^h}{N})^{n-2} (1 - \frac{\overline{n}^h}{N})^{mN-(n-2)} \tag{15}$$

This distribution has two parts:

1. Poisson
2. Binomial

In our work, we introduced a C++ script for the second scheme.

2 Method

In our approach, we tried fitting this multiplicity distribution function:

$$P_n = \sum_{m=1}^{M_G} \frac{\overline{m}^m e^{-\overline{m}}}{m!} C_{mN}^{n-2} (\frac{\overline{n}_g^h}{N})^{n-2} (1 - \frac{\overline{n}_g^h}{N})^{mN-(n-2)}$$

and finding the 4 fitting parameters where:

1. $\overline{m}$ is the average multiplicity of gluons,
2. $\overline{n}_g^h$ is the Average multiplicity of hadrons that forms from a single gluon,
3. N is the Maximum possible number of hadrons that can be produced from a single gluon,
4. Ω is the Normalization coefficient

We used CERN's ROOT of version 6.20. "Minuit2" library which is a new object-oriented implementation of the popular FORTRAN's MINUIT minimization package was chosen for the fitting process.

3 Results And Discussion

Fitting was done using the four center of mass energies $\sqrt{s} = 100$, 102, 205, 300, 405 & 800 GeV, as shown in Figures 2-7. The red error bars represent the experimental data and the blue line represents the fitting equation. The obtained fitting parameters are shown in Table 1.

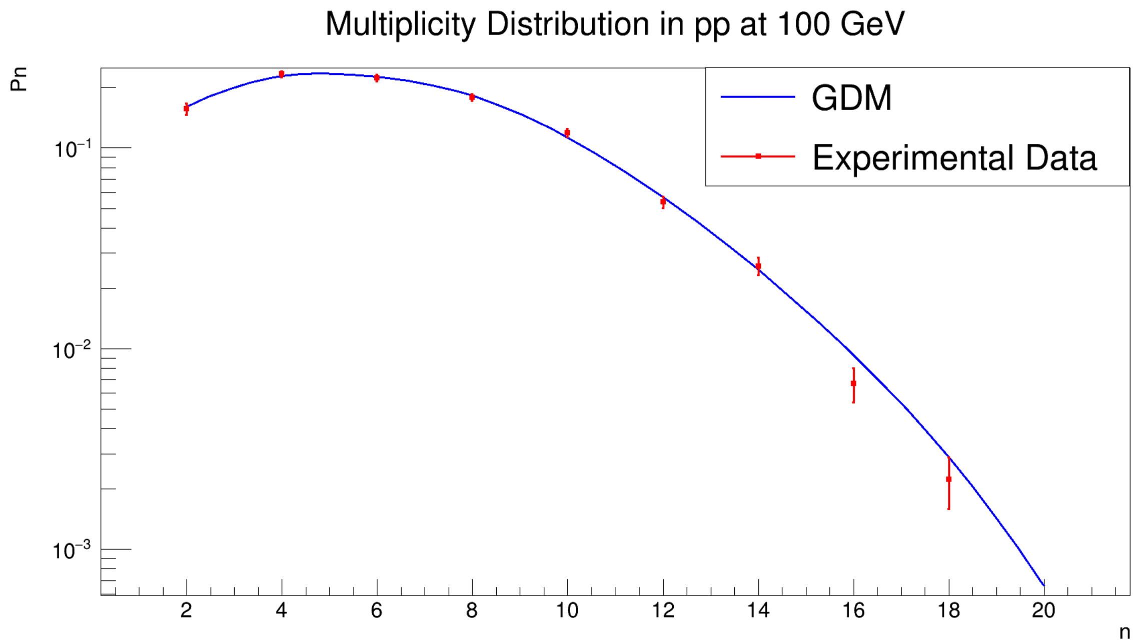


Figure 2

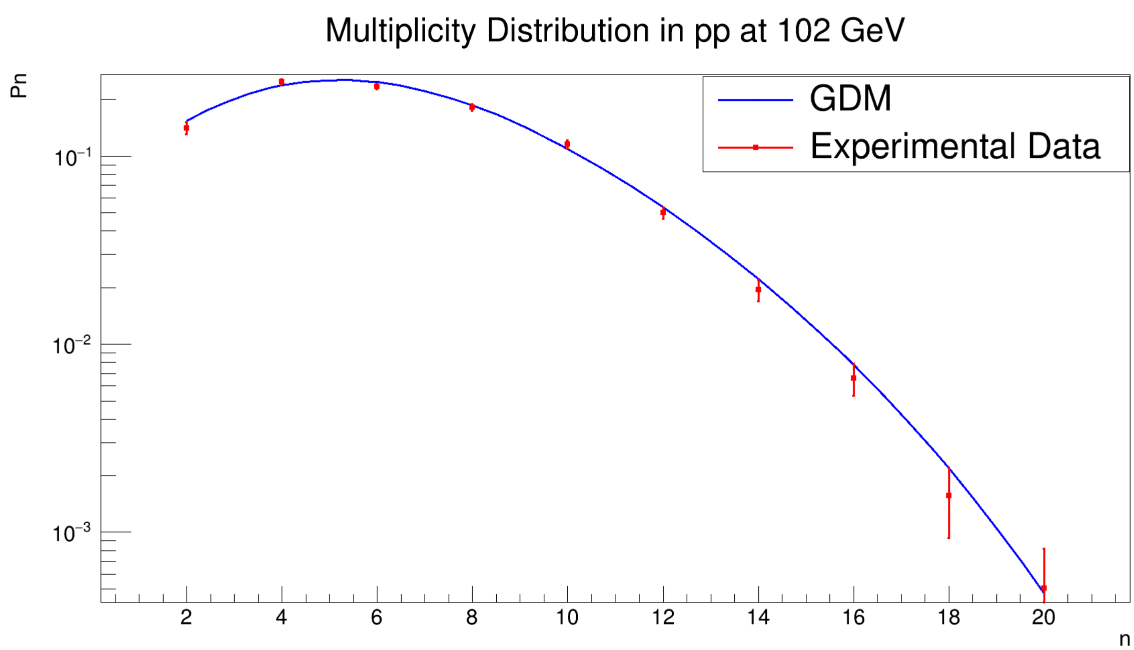


Figure 3

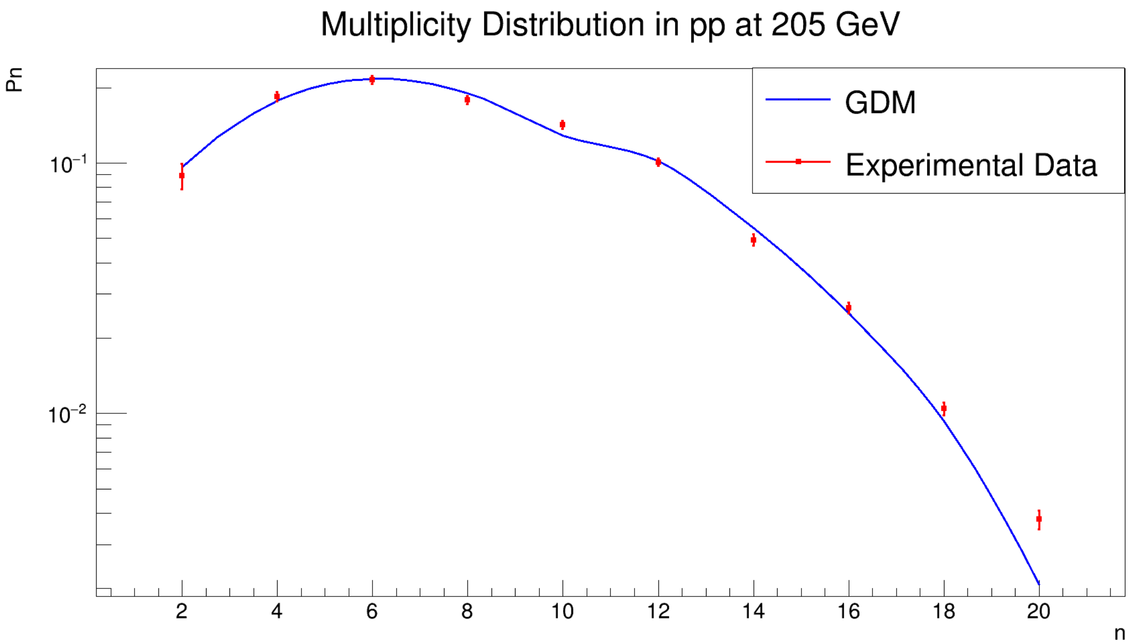


Figure 4

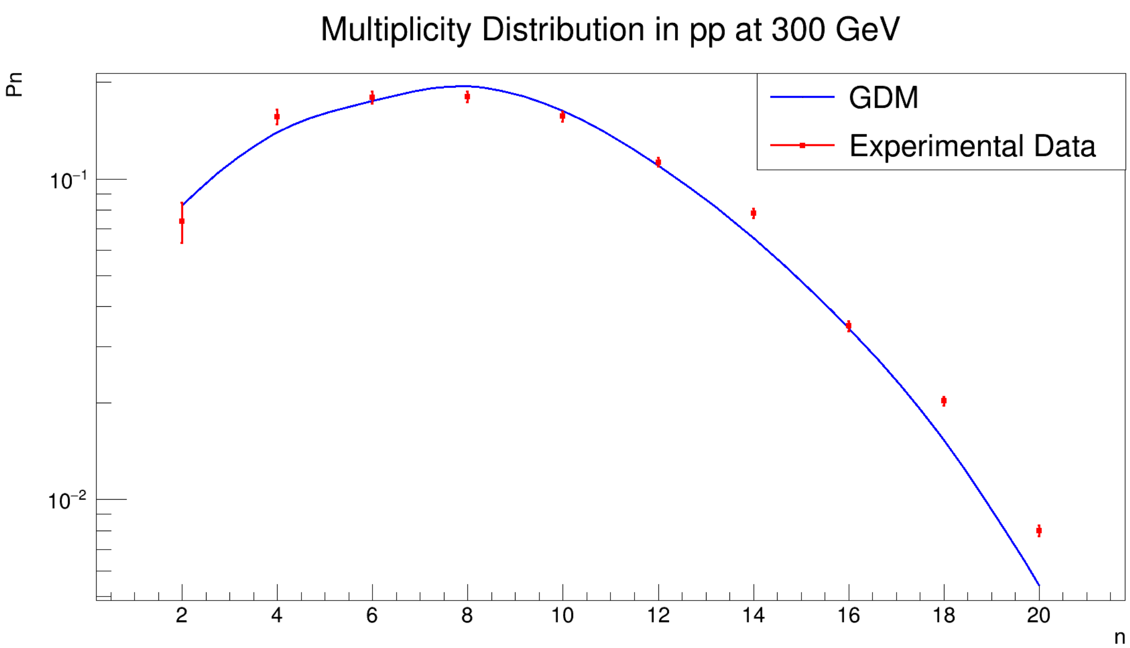


Figure 5

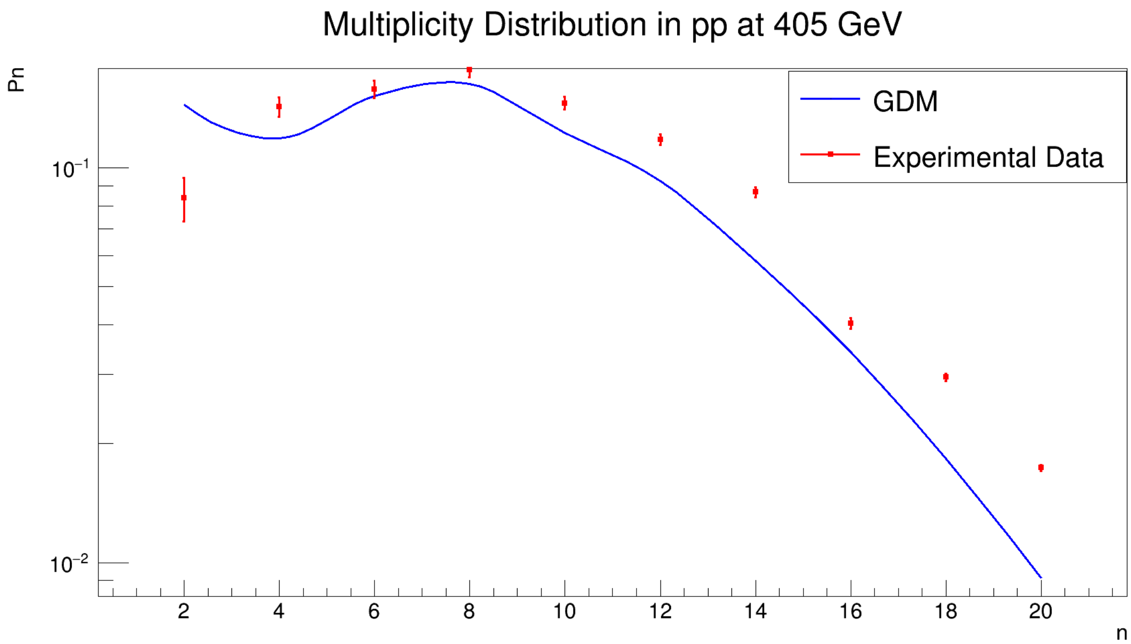


Figure 6

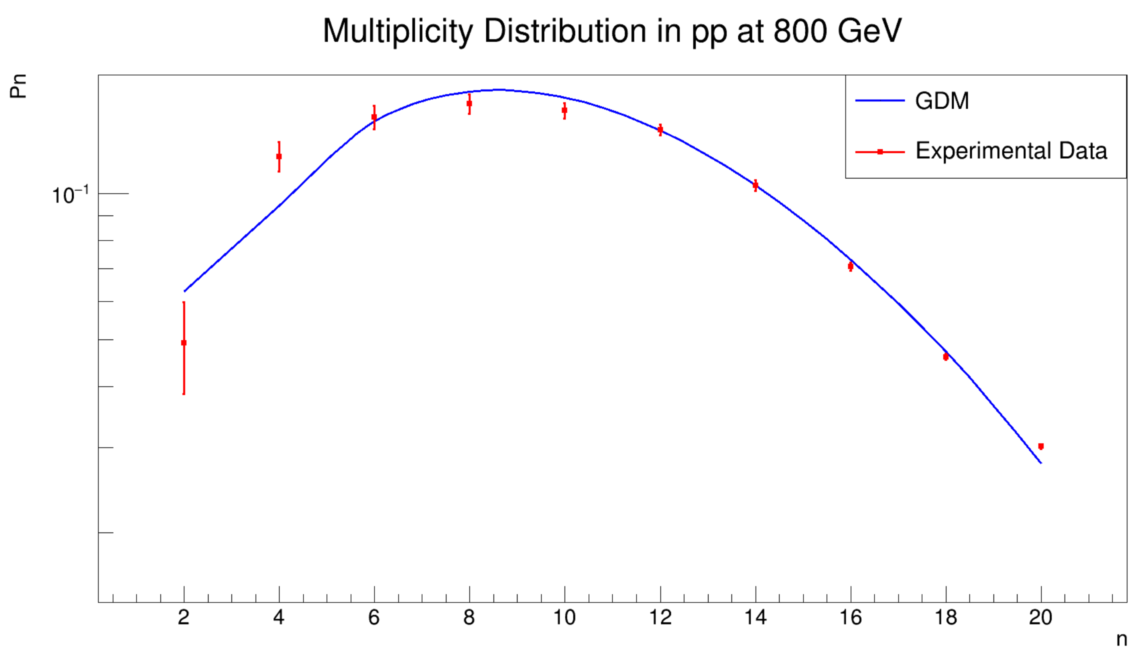


Figure 7

It is clear that there is a large error in some of the plots which is due to the extreme complexity of our equation. But the results are still acceptable.

	$\overline{m}$	N	n_g^h	Ω
$\sqrt{s} = 100\ GeV$	2.63385	3.04516	1.79633	1.88337
$\sqrt{s} = 102\ GeV$	2.94465	4.0	1.55729	1.94606
$\sqrt{s} = 205\ GeV$	3.0873	2.5	1.96167	1.97535
$\sqrt{s} = 300\ GeV$	3.27342	3.07311	2.0106	1.92441
$\sqrt{s} = 405\ GeV$	2.50494	4.00856	2.58951	1.70013
$\sqrt{s} = 800\ GeV$	1.81107	35.1364	0.309082	1.99668

Table 1: Parameters obtained using fitting

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