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Proton Fragmentation in High Energy Collisions

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Abstract:
Simulations of nucleon collisions based on the Lund fragmentation scheme are not fully satisfactory at present. Though succesful in reproducing meson spectra, they fail with respect to baryon spectra in the fragmentation regions. It is therefore reasonable to look for a more careful treatment of the diquark end in a fragmenting baryon string. In this paper we introduce a new version of the so called J-quark Model - a model of the inner structure of such a diquark. We show that simulations of pp-collisions using an algorithm taking this model into account improve fits to experimental data. Further improvements within the framework of this model are discussed.

1 introduction

It is believed that in heavy ion collisions, a quark plasma state could be achieved, i.e. for a short while the collision gives rise to an extended region where the energy density is large enough to destroy the confinement mechanism. Experiments with oxygen and sulfur nuclei have been performed, but the results give no definite proof for plasma states. Soon, experiments which hopefully give less ambiguous results will be performed. Brookhaven will reach higher energies than before, and CERN will be able to do experiments with lead, a very heavy nucleus. But in order to identify plasma events, there is a need for a reliable simulation of nucleus collisions, were there no plasma state involved.

Many models and Monte-Carlo computer programs designed for this exist. Their algorithms are normally built up in two steps: Choosing which partons actually interact and what energy-momentum they get when stretching a string is the first step, the fragmentation of the strings the second. One model of this type, which we will study below, is the FRITIOF model described in ref [1]. Executing the second step, many programs use JETSET [2] based on the Lund fragmentation scheme [3]. However, in later versions of JETSET the possible options for nucleon fragmentation are reduced. In many situations this may be of less importance, but in some cases - in particular in nucleus collisions - the results could be quite unrealistic. A diquark is treated as a structureless unit which inplies that baryon spectra are too hard, and can not be softened without hardening meson spectra too much. The new ideas presented in ref [4] also motivate further studies of diquark fragmentation.

In a previous model a diquark was treated with an inner structure described by a so called J-quark [3] - a model present in older versions of JETSET but lately removed. In this study we investigate to what extent experimental data can be better reproduced within the framework of this model.

2 Some aspects of the Lund fragmentation model

Yoyo motion

Quark-quark and quark-gluon interaction can be described by a so called colour field, which does not spread out in space as e.g. the electro-magnetic field, but is concentrated into a linear "colour flux tube", or a "string" [5, 6, 3]. The energy density of the field is constant. We can define a string constant κ so that the energy dE stored in a string segment of length dl is

$$dE = \kappa dl \tag{1}$$

Consider a meson of mass m at rest in a model where it is built up by two massless partons. Assume that at a certain moment the two partons are also at rest. Then there is no kinetic energy in the system and m has to be the potential energy. So $m = \kappa l$, the partons are a distance l apart, stretching a string in between. The string will pull the two partons together. As the string gets shorter the kinetic energy of the partons grow, keeping the total energy

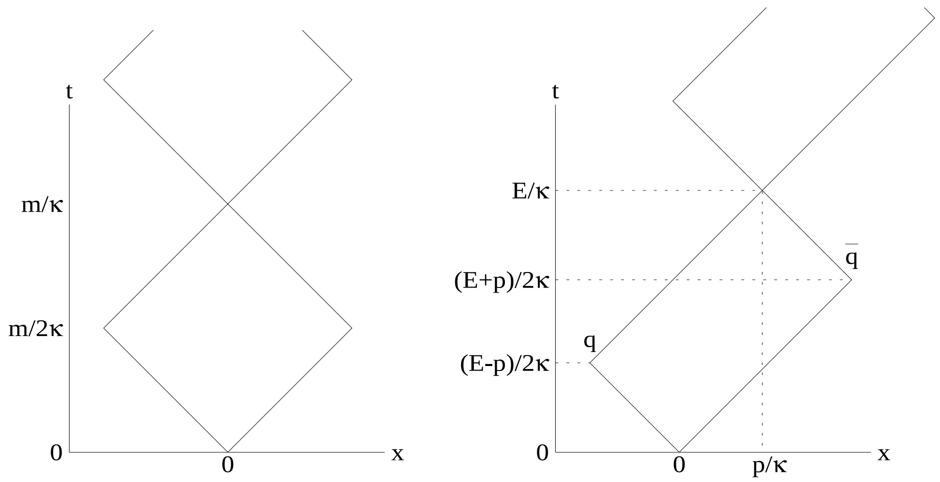

Figure 1: *Yoyo motion of partons in a meson at rest and a meson with momentum p.*

constant. Since the partons are massless in the model, they move with speed c. (From now on we will use units were c=1.)

The partons will be accelerated until they pass each other with a momentum $p = \pm m/2$. This happens after a time $l/2 = m/2\kappa$. (In Fig 1 this time is set to $t = 0$.) Then they move apart loosing momentum to the string stretched out between them until they again are a distance l apart. This motion is called the "yoyo motion". The motion is showed in Fig 1. The area of the figure is $(m/\sqrt{2}\kappa)^2 = m^2/2\kappa^2$. It is convenient to re-scale the figure so that the area is m^2/κ^2. Then in momentum space the area is m^2.

Boosting to a system where the meson has a momentum p and energy E, we can start our discussion when one of the partons, say the quark, is at rest and the anti-quark is moving towards the quark with momentum p. The string length is then given by $\kappa l = E - p$. At a certain time ($t = 0$ in Fig 1.) they will pass, but now with different momentum. The anti-quark carries more energy than the quark. When the quark has lost all its energy to the string and starts moving towards the anti-quark, the antiquark still moves away.

Important to notice is that the two areas in the two figures are the same! The line in the t+x direction, called the + direction, has the length (E+p)/κ, the line in the t-x direction, called the −direction, has the length (E-p)/κ. The area becomes $(E^2 - p^2)/\kappa^2 = m^2/\kappa^2$ in every Lorentz system. A boost is equivalent to stretching our figure out in the + or − direction, and compressing it in the other.

The partons can be assumed to move in other ways than the yoyo motion. Another model is the "revolving rod" where the partons rotate around each other stretching a field of constant length between them. The yoyo model is one of the simpler and the basis of the Lund fragmentation scheme.

String fragmentation

A $q\bar{q}$-pair can be created in the string. If the colour charges of the original partons (from now on called q_0 and $\bar{q}_0$) are the same as those of the new partons (say $r\bar{r}$), then q will be

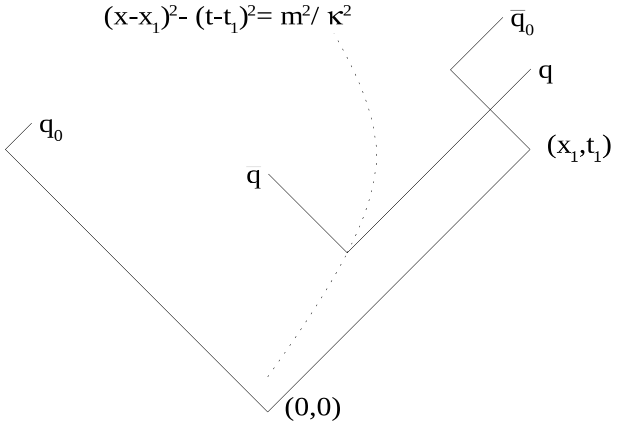

Figure 2: *An original string breaking into two strings*

pulled towards $\bar{q}_0$ and $\bar{q}$ towards q_0. In the region between the new partons there will be no string field. In this way we have fragmented the string into two strings, forming two mesonic systems, (Fig 2). Creating partons with colours different from those of the original system will be discussed in the popcorn model.

The $\bar{q}_0$ will not notice this string break at first. The force acting on it from the string is the same no matter how long the string is. The original partons will turn at the same positions as if there had been no break of the string. (When q passes $\bar{q}_0$ and changes the direction of the string between them, the motion of the original anti-quark will of course change.)

To create a meson of mass m, the break has to be on a hyperbola defined by

$$(x - x_1)^2 - (t - t_1)^2 = m^2/\kappa^2 \tag{2}$$

where (t_1, x_1) is the turning point of $\bar{q}_0$.

Several breaks of this kind can occur, producing several particles. We call the particle which contains the original parton moving in the + direction the *rank 1 particle*. In the figure this is meson $q\bar{q}_0$. The hadron containing $\bar{q}$ has rank 2, etc.

Working in momentum space we can define

$$W^+ \equiv E + p \tag{3}$$
$$W^- \equiv E - p \tag{4}$$
$$W^2 \equiv W^+W^- \tag{5}$$

W is then the invariant mass of the system.

So far we have worked in 1+1 dimensions, and this is also the frame of the Lund fragmentation scheme. Particles with transverse momentum are dealt with as if they only had longitudinal momentum and a mass $m_\perp$ given by $m_\perp^2 \equiv m^2 + p_\perp^2$.

Monte-Carlo algorithm
When simulating a fragmenting string we need algorithms for choosing the flavour of every new q$\bar{\text{q}}$-pair, choosing what hadron to be formed by the different partons, and what transverse momentum they should have. Deriving these is not the subject of this paper, but it should be mentioned that in the Monte-Carlo algorithm, the relative weight of different flavour production is

$$u : d : s : c \approx 1 : 1 : \frac{1}{3} : 0 \tag{6}$$

The $p_\perp$ of hadrons is picked from a Gaussian distribution.

In the algorithm we start at the turning point of the original parton going in the +direction. Given the $m_\perp$ of the hadron to be produced, we move down a fraction z^+ on the W^+ line and move in the –direction a fraction z^- of the W^--length. We have the condition $z^-W^-z^+W^+ = m_\perp^2$ and hence

$$z^- = \frac{m_\perp^2}{z^+W^2} \tag{7}$$

The energy and momentum of the created hadron will then be given by

$$E + p = z^+W^+ \tag{8}$$
$$E - p = z^-W^- \tag{9}$$

The fraction z^+ has to be picked from a distribution function. In the Lund model the *symmetric Lund fragmentation function* is used.

$$f(z^+) = N_{m_\perp}\frac{(1-z^+)^a}{z^+}exp(-\frac{bm_\perp^2}{z^+}) \tag{10}$$

a and b are free parameters and $N_{m_\perp}$ is a normalization constant. With proper choice of a and b, the model has been successful in reproducing experimental data.

3 J-quark model

The correspondence to the yoyo model for a baryon is a Y-shaped string with one parton in each end. Looking at the baryon at rest, we want the string junction to be at rest as well. In a Lorentz frame where the junction is at rest the strings stretch out in a symmetric way - the angle between the strings are 120°.

Suppose one of the quarks (The interacting quark, or "I-quark") collides with something and starts to move in a new direction. The information about this collision will move down the string with the speed of light and reach the junction at the same time as the other two quarks passes the junction. After this time there will be a "kink" on the string between the junction and the I-quark. The motion of the kink is parallel to the motion of the I-quark. The junction will now start to move. By boosting to a system where angles between the strings from the junction to the kink and the two non-interacting quarks are all 120°, we have found the rest frame of the junction and hence the motion of the junction in our original

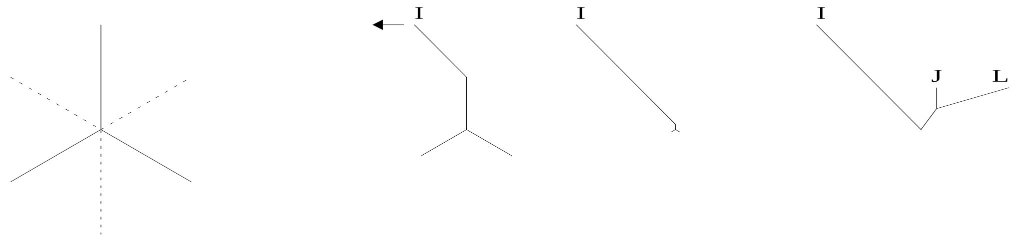

Figure 3: *Quark motion in a baryon at rest, and after a collision.*

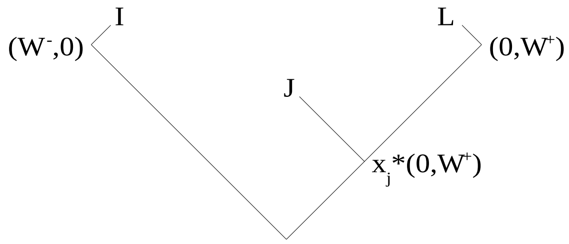

Figure 4: *Quark motion in a collided baryon. The picture is in the rest frame of the system* after *the collision. Coordinates are given in the (E-p,E+p) coordinate system.*

frame. It can in this way be shown that the junction will always be close to one of the quarks (The junction quark, or "J-quark".) After a fragmentation of the string they will end up in the same hadron. We can regard them as one unit, calling it all the "J-quark".

In a x-t diagram the development of the string looks like this (Fig 4): The I-quark moves in the −direction. The other two moves together in the +direction. At a time t, the J-quark turns and starts moving (with approximately the speed of light) in the −direction, while the last one (The leading quark, or "L-quark") continues in the +direction and turns at W^+. The J- and L-quark moves together a fraction x_j of W^+.

If in our first fragmentation we pick a $z^+ < 1 - x_j$ the rank 1 hadron will be a meson. If $z^+ > 1 - x_j$ it will be a baryon containing the J-quark. If we pick x_j from some distribution function $g(x_j)$, the properties of this function will affect our fragmentation result.

The distribution function $g(x_j)$ is impossible to determine from the model, but experimental data gives a hint. Very hard mesons can be produced if x_j is close to 1 or 0. In order to avoid too hard pion spectra a function of the form

$$g(x_j) \propto x_j^{\alpha}(1 - x_j)^{\beta} \tag{11}$$

where α and β are positive is reasonable. From Λ^0 and Δ^{++} spectra the exponents were suggested to be $\alpha = 1$ and $\beta = 10$ in the old J-quark model [7].

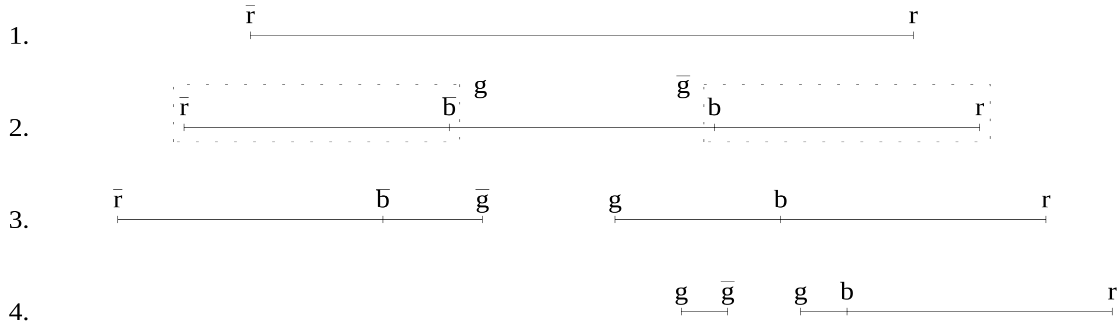

Figure 5: *Baryon - antibaryon production in the popcorn model.*

4 Popcorn model

The popcorn model is a model for baryon-antibaryon pair production by several $q\bar{q}$ productions. The idea is that a $q\bar{q}$ pair with "wrong" colour could be produced on the string. Say that a quark pair $q\bar{q}$ is produced between $q_0\bar{q}_0$. If $q\bar{q}_0$ (and thus $q_0\bar{q}$) can form two separate colour singlet systems, the string breaks. But if instead q_0q and $\bar{q}_0\bar{q}$ can form an anti-triplet state and a triplet sate respectively, a field of the same kind as the original string field is stretched between the two new partons. (see Fig 5.) Then the new partons can move freely along the string, pulled by equal forces to the left and to the right. But on the other hand we cannot conserve energy. The partons have masses and momentum and hence energy but we have not gained any energy by destroying the string field between them.

The phenomenom has to be considered a quantum fluctuation, which must develop to a "final" state of correct energy within a time determined from Heisenberg's uncertainty principle. This can be achieved either by letting the two partons meet and annihilate, or by creating new pairs in between with correct colours for the string to get cut. In the latter case we have created a baryon followed by an antibaryon. In this case the flavour coupling between the baryon and the anti-baryon is strong: Two partons in the anti-baryon have the anti-flavour corresponding to two partons in the baryon. We get the same flavour coupling as if the baryons were produced from a model of diquark-antidiquark production.

But there could also be created two $q\bar{q}$ pairs between our fluctuation-partons. That gives us a meson between the two baryons and a less strong flavour coupling between the baryon and the anti-baryon than in the case of diquark-antidiquark production. The possibility of producing three or more $q\bar{q}$ pairs thus creating two or more mesons between the baryons is exponentially suppressed in the model. The model has shown good agreement with experiments.

Going from step 3 to step 4 in Fig 5 shows many similarities to producing a leading rank meson in the diquark end of a fragmenting baryon string. In later versions of JETSET, the J-quark model has been replaced by this scheme. The probability of getting a leading rank meson when fragmenting a diquark then equals the probability of getting a meson between two baryons in the popcorn model. In this way we let one mechanism explain two different phenomena, and we get two parameters less to work with (i.e. the exponents of $g(x_j)$).

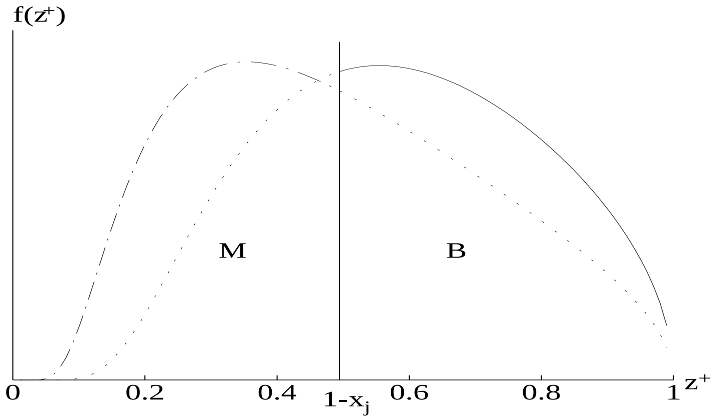

Figure 6: *z^+ distribution function for a typical baryon mass (full line to the right, dots to the left of $1-x_j$) and meson mass (dash-dotted line to the left, dots to the right of $1-x_j$). In this figure x_j is 0.5.*

Compared to the J-quark model, the popcorn model is a simplification of diquark fragmentation, in the sense that no constraint is imposed on the energy momentum fraction taken by the meson.

5 Re-introduction of J-quark model

Equal probability for meson- and baryon attempt

A hadron with transverse mass $m_\perp$ is given a z^+ according to the symmetric Lund function, Eq (10). Two such distributions are shown in Fig 6 for a typical baryon and meson mass respectively. When producing a leading rank baryon the probability for it to have $z^+ > 1-x_j$ is then given by the area B under the full line. Similarly, M under the dash-dotted line gives the probability for a rank 1 meson to have $z^+ < 1-x_j$. Since all other particles are rejected the probability of creating a particle in the J-quark model with $z^+ > 1-x_j$ should be $\frac{B}{B+M}$. If the probability for a baryon attempt is p, the rate of accepted baryons will be

$$\frac{pB}{1-(p(1-B)+(1-p)(1-M))} = \frac{B}{\frac{M}{p}+B-M} \tag{12}$$

Putting this expression equal to $\frac{B}{B+M}$ yields $p=\frac{1}{2}$.

Flavour and spin of new L-quark and LJ-diquark

The new L-quark should have the same flavour as the antiquark of the leading rank meson. The new diquark will be built up by this new L-quark and the J-quark. What is the spin of this diquark?

Say that the J-quark is a quark with flavour α and spin up. If the L-quark also is of flavour α, the possible diquark states are

$$\alpha\alpha_{11} = \alpha\!\uparrow \alpha\!\uparrow \tag{13}$$
$$\alpha\alpha_{10} = \frac{1}{\sqrt{2}}(\alpha\!\uparrow \alpha\!\downarrow + \alpha\!\downarrow \alpha\!\uparrow) \tag{14}$$

If the L-quark has a different flavour β the possible diquark configurations becomes

$$\alpha\beta_{11} = \frac{1}{\sqrt{2}}(\alpha\!\uparrow \beta\!\uparrow + \beta\!\uparrow \alpha\!\uparrow) \tag{15}$$
$$\alpha\beta_{10} = \frac{1}{2}(\alpha\!\uparrow \beta\!\downarrow + \alpha\!\downarrow \beta\!\uparrow + \beta\!\uparrow \alpha\!\downarrow + \beta\!\downarrow \alpha\!\uparrow) \tag{16}$$
$$\alpha\beta_{00} = \frac{1}{2}(\alpha\!\uparrow \beta\!\downarrow - \alpha\!\downarrow \beta\!\uparrow - \beta\!\uparrow \alpha\!\downarrow + \beta\!\downarrow \alpha\!\uparrow) \tag{17}$$

Only the terms beginning with $\alpha\!\uparrow$ can contribute. The relative weights of the states will then be

$$\alpha\alpha_1 : \alpha\beta_1 : \alpha\beta_0 = \frac{3}{2} : \frac{3}{4} : \frac{1}{4} = 1 : \frac{1}{2} : \frac{1}{6} \tag{18}$$

The relative weights between the flavour constellations are

$$\alpha\alpha : \alpha\beta = 1 : \frac{2}{3} \tag{19}$$

Thus, in the Monte-Carlo algorithm, a third of the meson attempts where the new L-quark and the J-quark have different flavours should be thrown away. [1]

E and p_L of partons

Given the transverse masses m_1 and m_2 of the partons together with W^+ and W^- of the total string system we get the relations (dropping the L subscript on p_{L1} and p_{L2})

$$E_1 + E_2 = \frac{1}{2}(W^+ + W^-) \tag{20}$$
$$p_1 + p_2 = \frac{1}{2}(W^+ - W^-) \tag{21}$$
$$E_1^2 - p_1^2 = m_1^2 \tag{22}$$
$$E_2^2 - p_2^2 = m_2^2 \tag{23}$$

Substituting the first three into the last one yields

$$E_1 = \frac{1}{W^+ + W^-}\left[\, p_1(W^+ - W^-) + W^2 + m_1^2 - m_2^2 \,\right] \tag{24}$$

[1] This applies only for the new L-quark which finally ends up in a baryon together with the J-quark. However, in the algorithm used it is done for every meson attempt. This favours production of π^0 and ρ^0 as compared to $\pi^{+/-}$ and $\rho^{+/-}$. The effect is not negligible, but the main interest of this paper is the study of baryon spectra compared to meson spectra. The relative baryon/meson production should not be significantly affected.

which put into Eq (22) gives, after some algebra

$$p_1 = \frac{1}{4W^2}\left[(W^+ - W^-)(W^2+m_1^2-m_2^2) \pm (W^+ + W^-)\sqrt{(W^2+m_1^2-m_2^2)^2 - 4W^2m_1^2}\right] \quad (25)$$

If we want particle 1 to go in the z^+ direction we choose the positive sign in front of the square root. From p_1 we easily get the other energy and momentum values.

Rate of s-quark pair production

In the current model producing u- d- and s-pairs with the relative ratio 3:3:1 approximately, has shown good agreement with experiments. In the J-quark model there is a difference between the probability of trying to produce a $s\bar{s}$ pair and the relative number of produced pairs. This can be explained in the following way:

Look at Fig 6. Say that in $u\bar{u}$ and $d\bar{d}$ pair productions the typical meson- and baryon masses are approximately the same, but $s\bar{s}$ production give rise to other masses and therefore two new areas M_s and B_s. If the probability to try a s-pair production is p, the probability p' to accept a s-pair is

$$p' = \frac{\frac{p}{2}(M_s + B_s)}{1 - \frac{1-p}{2}(1-M+1-B) - \frac{p}{2}(1-M_s+1-B_s)} = \frac{p}{p + A(1-p)} \quad (26)$$

where A is the area ratio $\frac{M+B}{M_s+B_s}$. If A=1 then p'=p. Since $p < 1$ we get

$$\frac{dp'}{dA} = -\frac{p}{[p + A(1-p)]^2}(1-p) < 0 \quad (27)$$

If $M_s + B_s < M + B$ then $A > 1$ and $p' < p$.

Taking into account the construction of a new LJ-diquark used in the present algorithm, we have to multiply by the factor 2/3 in front of the M areas when the flavour of the produced quark differs from the one of the J-quark. (See footnote page 8.) Since the J-quark is never an s-quark in proton fragmentation, we get the replacements

$$M \rightarrow \frac{1}{2}\left[M + \frac{2}{3}M\right] = \frac{5}{6}M \quad (28)$$

$$M_s \rightarrow \frac{2}{3}M_s \quad (29)$$

Simulations indicate $p' < p$. Calling the JETSET default probability p_0, this suggests a choice of $p > p_0$ to get $p' \approx p_0$. However, some aspects of the model which suppress $s\bar{s}$ production are not included in the algorithm so far. (See section 8.) To compensate for this $p \approx 0.85p_0$ is used in the simulations below.

6 Monte-Carlo algorithm of the model

First of all we pick one of the partons in the diquark to be the J-quark. In the algorithm we will with equal probability try to produce a rank 1 baryon and a rank 1 meson. (See section 5.) These two attempts will be referred to as "baryon attempt" and "meson attempt" respectively.

In a baryon attempt we fragment the string built up by the original diquark and quark. The fragmentation is repeated until the rank 1 hadron is indeed a baryon. (this is not always so when using a JETSET version creating rank 1 mesons according to the popcorn parameters as discussed above.) If the baryon energy-momentum fraction z^+ is greater than $1 - x_j$ the fragmentation is accepted. Otherwise the whole attempt is rejected and a new one will be done, with equal probability for making a baryon or meson attempt. Thus we will only get rank 1 baryons with $z^+ > 1 - x_j$.

In a meson attempt we build up the string of the L-quark and a new diquark which consists of the I- and J-quark [2]. Sending the L-quark in the diquark direction we get a rank 1 meson. If the rank 1 hadron nevertheless is a baryon, due to the popcorn mechanism, we make a new meson attempt.

Behind the rank 1 meson, the rest of the jet will get a new L quark which will form a new LJ-diquark. This new diquark is not always accepted, and if not we make a new meson attempt. (see section 5.)

Once we have overcome these obstacles, we look at z^+. If $z^+ > 1 - x_j$ we make a new fragmentation, either a baryon- or meson attempt. If $z^+ < 1 - x_j$ the meson is accepted, and we take a closer look at the rest of the jet.

The W_r^+, W_r^- and x_{jr} of the remaining jet is calculated as follows:

$$W_r^+ = W^+(1 - z^+) \tag{30}$$

$$W_r^- = W^-(1 - z^-) = W^-(1 - \frac{m_\perp^2}{z^+ W^2}) \tag{31}$$

$$x_{jr} = \frac{x_j}{1 - z^+} \tag{32}$$

After an accepted meson attempt we normally re-fragment the rest jet according to the same algorithm. This is not done if it is impossible or unnecessary to do a re-fragmentation:

*The total energy W must be big enough to contain the new partons with their transverse masses. The new transverse momentum is calculated as follows: In the I-quark end it is never changed. In the L-quark end the transverse momentum of the rank 1 meson is subtracted, thus conserving the total transverse momentum. If $W < (m_1 + m_2)$, where m_i is the transverse mass of the string's two partons respectively, it is impossible two conserve energy and momentum, and re-fragmentation is not done. The complete latest fragmentation is saved as the final result.

*If the string only fragmented into two hadrons there is no need for a new fragmentation.

[2] When constructing the IJ-diquark to be used in the I-quark end of the string in meson attempts, spin is always set to 1, avoiding unphysical diquarks. This simplification is due to the fact that in the general case when a string system has been set up, we don't know the spin of the original hadron. Only if the J-quark ends up in one of the last rank hadrons IJ-spin could effect the final result.

7 Results

To test if the model improves fit to baryon spectra without hardening meson spectra too much, proton fragmentation has been studied. The new J-quark model has been applied to JETSET 7.3. The results have been compared to unmodified JETSET 7.3. Simulations in FRITIOF 7.02 - which is using JETSET 7.3 - have been made for pp collisions.

Fragmentation of a single diquark-quark system is not expected to give a very accurate description of proton fragmentation in hadronic cololisions. Nevertheless it can be useful when studying the α and β dependence of the fragmentation model. The result from such studies are shown in Fig 7 and Fig 8. Experimental data are also included, though only to guide the eye.

Keeping the ratio β/α constant, the most likely x_j which is $\frac{\alpha}{\alpha+\beta} = \frac{1}{1+\beta/\alpha}$ remains constant. The main difference between the simulations is then the spread of $g(x_j)$. This is studied in Fig 7 for $\beta/\alpha = 1$. As expected the meson spectra get softer when α and β grows. Changing the ratio β/α, we see in Fig 8 that baryon spectra have a more and more prominent top at low x as the ratio increases, while mesons are affected in different ways. Most meson spectra (especially K^+) get harder while K^- are rather insensitive but get somewhat softer as the ratio grows.

Comparing to experimental data, it has shown difficult to find values of α and β which give acceptable fit to both baryon and meson spectra. Looking at K^+ in Fig 7 implies $\alpha \approx \beta$, but spectra of Δ^{++} in Fig 8 suggests $\beta/\alpha \approx 4$. There also seems to be created far to many Λ^0, whatever parameters are chosen. In a FRITIOF simulation - which is a more realistic description of hadronic collisions - some of the problems disappear. K^+ gets less sensitive to the exponent ratio, and there are fewer Λ^0 produced, as shown in Fig 9.

In the FRITIOF simulations, gluon production is neglected due to algorithmic problems. At the low energies used ($\sqrt{s} \approx 30GeV$) this have little effect on the distributions studeied here.

Choosing $1 < \beta/\alpha < 3$ improves the results from simulations, as compared to JETSET 7.3 (and FRITIOF 7.02) without the J-quark model. Examples are shown in Fig 10. Although reduced, the problem of getting either too hard mesons or too hard baryons remains to some extent. This will be discussed in the following section.

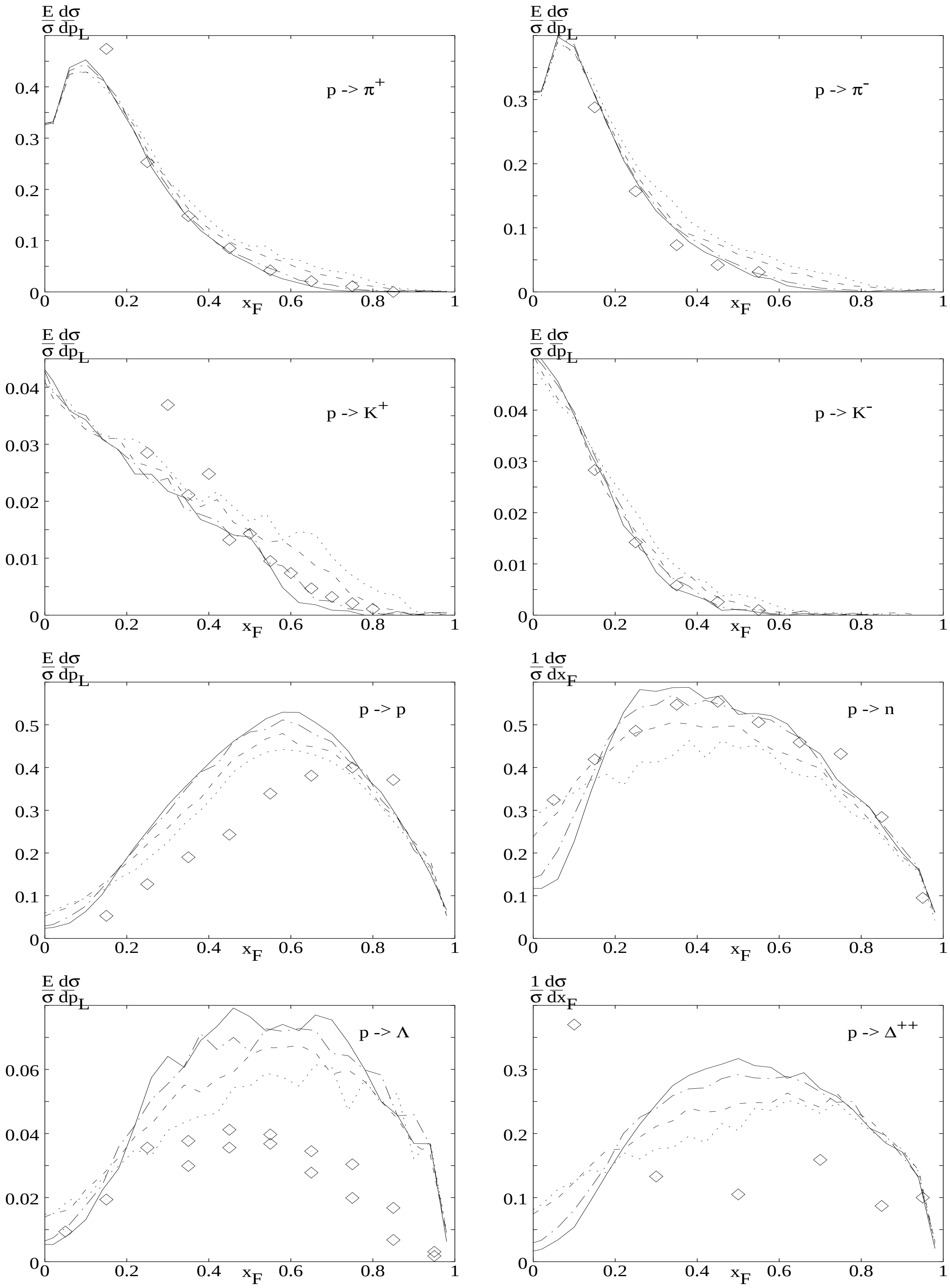

Figure 7: *Dependence on values of α and β, keeping the ratio β/α constant =1. Spectra at W=11Gev from 7.3 J-quark model with $\alpha = \beta$ =10 (full line), =5 (dash-dotted), =1 (dashed) =0 (dotted). Experimental data from* [7] *(Δ^{++}) and* [3] *(others) are included as diamonds, though the figure is mainly for comparison of results from different simulations.*

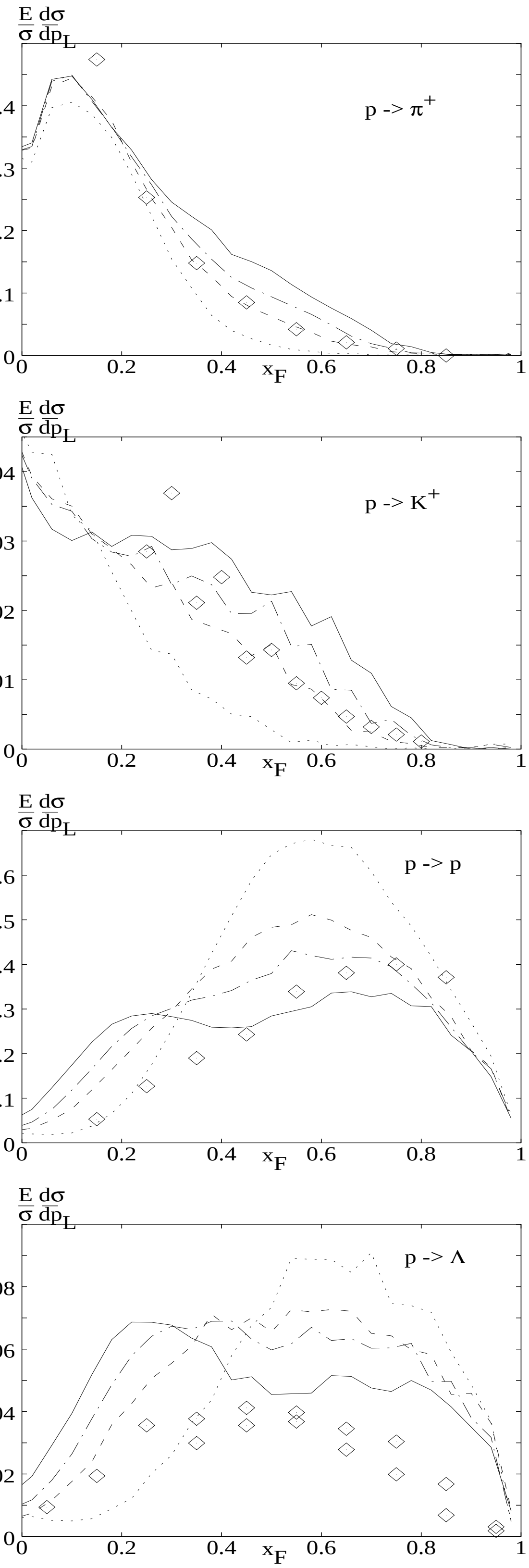

Figure 8: *Dependence on the ratio β/α. Spectra at W=11Gev. Lines are simulations with $\alpha = 5$ and: $\beta = 10$ (full), $\beta = 7$ (dash-dotted), $\beta = 5$ (dashed), $\beta = 1$ (dotted). Experimental data from [7] (Δ^{++}) and [3] (others) are included as diamonds, though the figure is mainly for the comparison of results from different simulations.*

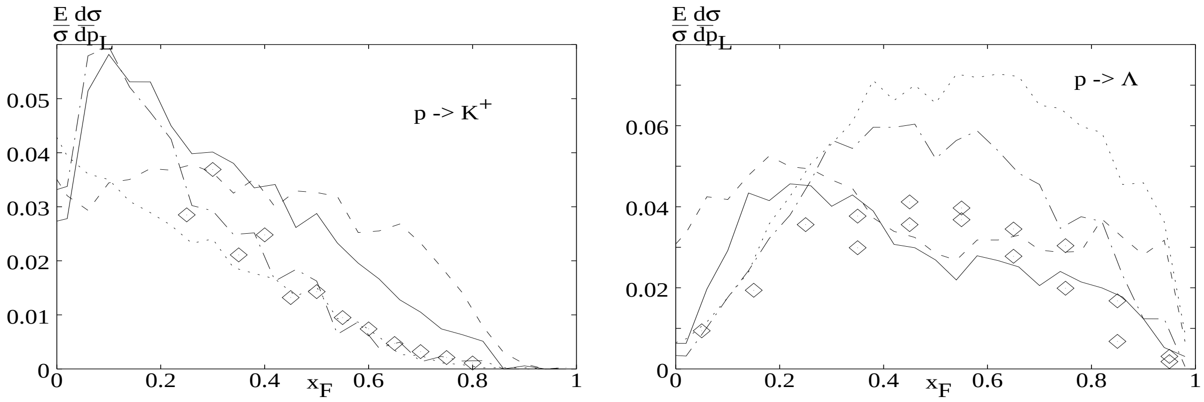

Figure 9: *Comparison FRITIOF 7.02 pp collision, s=900GeV, and JETSET 7.3 proton fragmentation at 11GeV. Lines are α=1 β=5 FRITIOF (full) and JETSET (dashed), α=β=5 FRITIOF (dash-dotted) and JETSET (dotted). Diamonds are experimental data* [3].

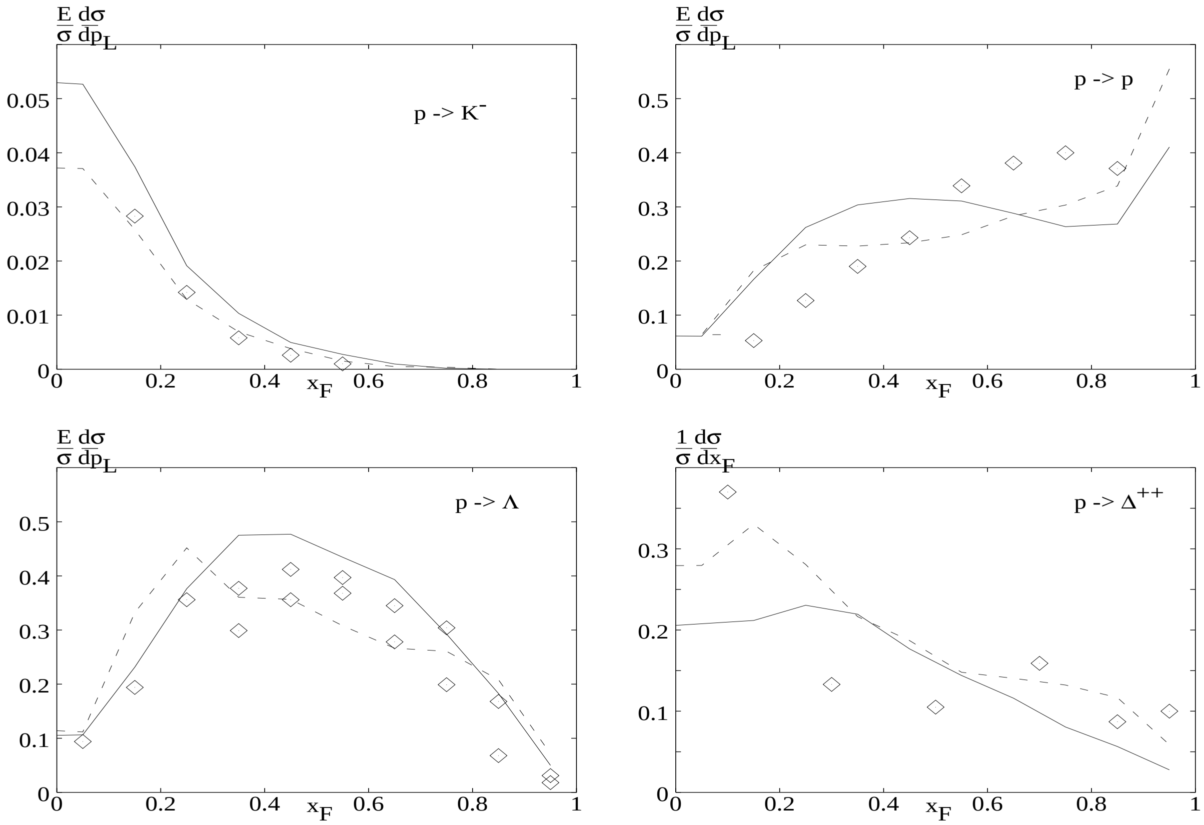

Figure 10: *FRITIOF 7.02 simulation of pp collision, s=900GeV. Full line is unmodified version, dashed line version with J-quark model and parameters α=2 β=5. Diamonds are experimental data from* [7] *(Δ^{++}) and* [3] *(others). Except for* K^-*, meson spectra get harder in the J-quark model.*

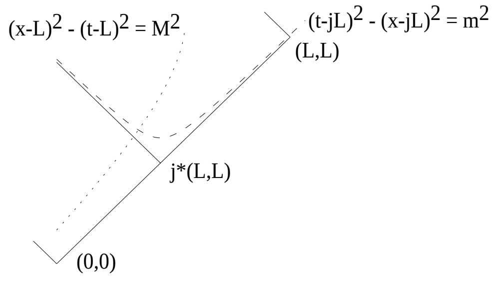

Figure 11: *Derivation of finite string length conditions.* x_j *is denoted by* j.

8 Possible improvements

There is a conflict between baryon- and meson spectra when choosing α and β of $g(x_j)$. Best fit for baryons give too hard mesons. One might overcome this problem when looking more carefully at the fragmentation close to the J-quark.

J-quark mass corrections

Presently, the limit between the regions of meson and baryon production is an infinitely thin line at x_j (Fig 6). A more appropriate model is to have a "no-mans-land" region around x_j where both meson- and baryon production is forbidden.

As shown in Fig 4, we assume in the model that the junction moves with the speed of light, i.e. we treat the junction, J-quark and the string between them as a massless object. If not doing this approximation, we get new contraints on z^+ for baryons and mesons. It implies a softening of the meson spectra. As the J-quark in this case always has a finite value for $E + p_L$, the maximum value of z^+ for a meson is less than 1. Thus if x_j is still defined as $1 - z^+_{max}$ for a meson the x_j distribution does not extend down to $x_j = 0$. Furthermore the motion of the massive J-quark will not be in the −direction, so z^+_{max} for a meson will depend on the mass of the produced meson. In the same way the $E + p_L$ of the J-quark implies a minimum value of z^+ for a baryon which contains the J-quark. For a first rank baryon it implies

$$z^+_{min}(first\ rank\ baryon) = 1 - x_j + \delta x_j \tag{33}$$

with some positive finite δx_j. An implementation of such constraints in the Monte-Carlo algorithm could result in a softenig of meson spectra without noticeably changing the baryon spectra, thus giving better agreement with experiments.

Finite string length

There has to be a finite string length between the J-quark and the position of pair production. A pair with total mass m must be produced a distance δl apart so that $\kappa\delta l \simeq m$, where κ is the string tension constant. Both partons in a pair has to be on the same side of the J-quark. This again leads to conditions of the type $z^+ > 1 - x_j + \delta x'_j$ for baryons and $z^+ < 1 - x_j - \delta x'_j$ for mesons.

$\delta x_j'$ can be estimated as follows: When creating a meson with transverse mass M, the q$\bar{\text{q}}$-pair must be produced on the hyperbola (using units such that κ is 1)

$$(x - x_1)^2 - (t - t_1)^2 = M^2 \tag{34}$$

where (t_1, x_1) is the turning point of the (massless) L-quark. Hence $x_1 = t_1 \equiv L$. The J-quark will then turn at a point $x_j * (L, L)$. The finite string length condition can be written $\tau > m$ [3, p 72ff] where m is the quark mass and τ is the proper time between the production vertex and the origin of the relevant string system. If $\tau < m$, the production is strongly suppressed. Measuring τ from the J-quark turning point the condition reads:

$$(t - x_j L)^2 - (x - x_j L)^2 > m^2 \tag{35}$$

Eq (34) and (35) give

$$t^2 - x^2 > m^2 + x_j(M^2 + t^2 - x^2) \Leftrightarrow t^2 - x^2 > \frac{m^2 + x_j M^2}{1 - x_j} \tag{36}$$

Using

$$t^2 - x^2 = z^- W^2 - M^2 = M^2(\frac{1}{z^+} - 1) \tag{37}$$

we get

$$\begin{aligned} (1 - z^+)(1 - x_j) &> (m/M)^2 z^+ + x_j z^+ && (38) \\ \frac{1 - x_j}{1 + (m/M)^2} &> z^+ && (39) \end{aligned}$$

But $z^+ < 1 - x_j - \delta x_j'$ and therefore

$$\delta x_j' \sim \left[1 - \frac{1}{1 + m^2/M^2}\right](1 - x_j) = \frac{1 - x_j}{M^2/m^2 + 1} \tag{40}$$

While the J-quark mass correction δx_j only depends on the energy of the J-quark, $\delta x_j'$ depends both on x_j and M/m. partons with large m will get the largest $\delta x_j'$. This leads to a suppression of s$\bar{\text{s}}$ pair production. When trying to create a K meson by s$\bar{\text{s}}$ production we have $m \sim 0.3$ GeV, $M \sim 0.5$ GeV, and $\delta x_j' \sim \frac{1}{4}(1 - x_j)$.

9 Summary

In order to improve simulations of baryon fragmentation - important e.g. in heavy ion collisions - we have studied a model for diquark fragmentation based on the J-quark scheme. In the model the diquark in one end of a fragmenting baryon string separates into a leading L-quark and a so called J-quark. The position of this separation determines what energy-momentum fractions are possible for produced baryons and mesons respectively, and is defined by the variable x_j. We let x_j be given by a distribution function $g(x_j) \sim x_j^\alpha (1 - x_j)^\beta$.

Using this model when simulating pp-colisions in FRITIOF and choosing $\alpha = 2$ and $\beta = 5$ we reproduce baryon spectra at a much better accuracy, but get somewhat too hard meson spectra. We hope to overcome this problem by treating the J-quark as a massive object and by implementing the finite stringlength conditions of the Lund fragmentaion model also to the region around the J-quark.

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