1. INTRODUCTION

When two high-energy hadrons collide one against another usually their entire volumes or at least a significant part of them participate in the collision. Such collisions are often called "soft" hadronic collisions. It may happen, however, that during a collision of two hadrons only one pointlike constituent from one hadron interacts with a similar constituent from the other hadron. The remaining parts of both hadrons do not participate in the first stage of the collision and are called spectators. These types of collisions are called "deep inelastic" or "hard" hadronic collisions. In this case a hadron may be considered as a beam of hadronic constituents called partons. They are flying with different longitudinal momenta described by the structure function $F(x)$, where $x$ is the longitudinal momentum of a parton divided by that of an entire hadron. At energies accessible at present to experiments, the constituents of hadrons may be considered as structureless, pointlike particles.

When two partons collide only two processes may occur. The first one is the elastic scattering. For initial parton momenta and scattering angles large enough, the scattered partons gain transverse momenta exceeding significantly those observed for secondary hadrons produced in soft hadronic collisions. Consequently the elastic scattering of partons is largely responsible for the production of hadronic jets and hadrons with large transverse momenta. The existence of such hadrons was predicted more than a decade ago [1] and observed experimentally at the CERN Intersecting Storage Rings (ISR) shortly afterwards [2].

The second process which may occur in the collision of two partons is their annihilation providing one parton is an antiparticle of the other one. The parton annihilation may be the origin of many different final states, e.g.:

- Another parton-antiparton pair. This brings additional contribution to the production of large $p_T$ hadrons or jets;

- A charged lepton-antilepton pair. This type of parton annihilation is called the Drell-Yan process [3].

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A heavy quark–antiquark pair. It may be observed as the associated production of heavy flavour hadrons or the production of heavy quarkonium states.

Although there is a large variety of processes due to hard hadronic collisions, most of the contributions submitted to this conference are dealing with the production of large transverse momentum hadrons and hadronic jets. This problem will be, consequently, treated more extensively in the present review. However, there are also interesting contributions to the conference with new results on the production of charged lepton pairs and of J/ψ mesons which are bound systems of charm–anticharm quarks. We will start with the discussion of these experiments on parton–annihilation reactions.

2. ANNIHILATION OF PARTONS INTO CHARGED LEPTONS AND HEAVY QUARKS

The annihilation of partons into a pair of charged leptons in the final state is the simplest process out of all hard hadronic interactions. At energies available at present, the annihilation is due to the electromagnetic interaction of a charged quark with an antiquark. It has been originally proposed that the diagram shown in fig. 1 should dominate the process [3]. If it were true, only the knowledge of structure functions of quarks and anti–quarks of colliding hadrons would be needed to predict the lepton–pair production cross section. However, experiments have shown that in reality the situation is more complicated. The main discrepancy between the simple prediction and experiments is the total cross section which was found bigger by more than a factor of two than the predicted value. Also the transverse momenta of lepton pairs are much larger than expected.

![Fig. 1](image)

The experimental results on lepton–pair production and their interpretation are reviewed in [4] and the reader is asked to look there for a more detailed discussion. The brief conclusion of it is that more complicated mechanisms have to contribute in addition to that shown in fig. 1. Some of them are sketched in fig. 2.

![Fig. 2](image)
The additional diagrams increase the predicted total cross section and may also explain large transverse momenta of the produced lepton pairs. However, they do not modify strongly the shape of the dilepton mass spectrum and that of the longitudinal momentum distribution. We can therefore, use experimental results on lepton pair production to determine the shape of the structure function of unstable hadrons which cannot be studied with deep inelastic lepton collisions [5].

It has been shown experimentally in studies of deep inelastic lepton-nucleon interactions that the structure function of a nucleon varies with the four momentum transfer squared, $Q^2$ [5]. Using the QCD guide line, a good parametrization of this scale breaking effect has been given by A. Buras and K. Gaemers [6]. The results on the production of muon pairs presented at this conference by the NA10 Collaboration [7] indicate that a similar scale breaking is present in the structure function of a pion. The analysis is based on 110,000 muon pairs with a dimuon mass above 4.5 GeV/c² produced by 194 GeV/c² $\pi^-$'s on a tungsten target. The high statistics of muon pairs allows to study their x distribution for dimuon masses up to 15 GeV/c². The quantity x is the longitudinal momentum of a pair divided by the maximum momentum in the pion-nucleon c.m.s. The main result of the experiment is displayed in fig. 3 where the x distributions are plotted for different dimuon mass intervals.

The full line represents the results of a fit to experimental points for $4.5 < M < 8.5$ GeV/c² with a $Q^2$ dependence included in the structure function of a pion. Again the Buras Gaemers parametrization has been used to take into account the scale breaking effect. It can be seen that the fit gives a good description of the data for dimuon masses up to 8.5 GeV/c². However, it fails to reproduce the data when extrapolated to masses above 11 GeV/c². It is possible that for such big masses the QCD scale breaking effects are still stronger than foreseen by the parametrization used. The other reason for the observed discrepancy may be due to nuclear effects or to the influence of the phase space limitations.

Fig. 3 - The x distributions of pairs for different dimuon mass intervals.
It has been already mentioned that in addition to the diagram shown in fig. 1, those of fig. 2 are important for the production of charged lepton pairs. They are needed to explain the magnitude of the measured cross section and large transverse momentum of lepton pairs. However, a more direct evidence for such diagrams would increase the confidence in our understanding of the process. The contributions from diagrams shown in figs 2(b) and (c) should manifest themselves e.g. by balancing the transverse momentum of a lepton pair with the fragments of a recoiled quark (anti-quark) or with those of a gluon. The CERN-Michigan-State-Oxford-Rockefeller Collaboration [8] presented the data on secondary particles produced in proton-proton collisions at 63 GeV c.m. energy in association with an electron-positron pair with a mass exceeding 11 GeV/c\(^2\). The observed masses extended up to 24 GeV/c\(^2\) and have been produced with the average transverse momentum, 
\[
\langle p_T \rangle = 2.3 \pm 0.4 \text{ GeV/c}.
\]
The data show that the transverse momentum of an electron pair is balanced by secondary particles collimated around 180° in azimuthal angle with respect to the azimuthal direction of a pair (fig. 4). The multiplicity of secondary hadrons increases with the pair transverse momentum. Both features agree with the qualitative expectations if lepton pairs recoil against quarks or gluons according to diagrams shown in figs 2(b) and 2(c).

The production of the charged lepton pairs in the first order is not sensitive to the gluon structure functions of colliding hadrons. Contrary to that, the production of heavy-flavour quark-antiquark pairs depends on both the gluon and quark structure functions. Taking their quark component from other experiments, we can then deduce the gluonic part from the observations of a heavy quark-antiquark system. The NA3 collaboration has submitted to this conference a contribution on the extensive study of the \(J/\psi\) production by different hadron beams on hydrogen and platinum targets [9]. By using two different targets, the collaboration has been able to show that there exist two mechanisms responsible for the production of \(J/\psi\) mesons: a hard component which shows a nearly linear dependence of the cross section on the atomic number, \(A\), and a soft, diffraction-like component with an atomic number dependence close to \(A^{2/3}\). The main mechanisms responsible for the hard production of \(J/\psi\) are two "parton annihilation" processes are shown in fig. 5.
They are often called "quark fusion" and "gluon fusion" reactions. The \( x \) distributions of \( J/\psi \) mesons produced via hard collisions have been obtained for different hadronic beams after subtracting the diffraction-like contribution. These distributions have been then used to determine the gluonic structure functions of two colliding hadrons. The quark-antiquark components of the hadronic structure have been taken from deep inelastic collisions and Drell-Yan processes. They determine the contribution from the quark fusion diagram. The gluon fusion contribution depends on the gluon structure functions, parametrized in the form \( A_p(1 - x)G_p \) and \( A_w(1 - x)G_w \) for a proton and a pion respectively. The data on \( J/\psi \) production in proton-proton and proton-antiproton collision have been used to determine \( g_p \). This value has been taken for the analysis of the pion-proton data in order to find the value of \( g_w \). The obtained result is

\[
\begin{align*}
g_p & = 5.1 \pm 0.2 \text{ (stat.)} \pm 0.1 \text{ (syst.)} \\
g_w & = 2.38 \pm 0.06 \text{ (stat.)} \pm 0.1 \text{ (syst.)}
\end{align*}
\]

We will end this section with a remark that it did not pretend to give a review of hard hadronic processes due to the parton annihilation. We have underlined only a few new results which have marked a progress in this field since the 1982 High Energy Physics Conference in Paris. They are:

- Experimental indication that the structure function of a pion shows a scale breaking effect [7].

- Observation that the transverse momentum of the high-mass electron pairs is balanced by secondary particles which may be fragments of a recoiled quark or a gluon [8].

- Determination of the gluon structure functions of protons and pions [9].

3. LARGE TRANSVERSE MOMENTUM COLLISIONS OF HADRONS

This year passes the decade since the first experimental observation of the production of large transverse momentum hadrons in high-energy proton-proton collisions [2]. The production of such hadrons has been predicted
as the consequence of the large angle scattering of two partons [1]. This original interpretation has been widely confirmed experimentally during last ten years.

Hadronic collisions with the production of large transverse momentum hadrons or hadronic jets allowed us to study parton–parton interaction, the parton structure of hadrons and the fragmentation of partons when they are ejected outside the parent hadron. Many contributions submitted to this conference brought new important results on all these questions. In the present section we will discuss these results and in particular the following aspects of large $p_T$ hadronic collisions:

- Inclusive cross sections for the production of large transverse momentum jets and hadrons.
- The nature of scattered partons.
- The mechanism of two-parton scattering.
- Some aspects of the fragmentation of partons.

The more extensive review of the last subject has been already presented at this conference by P. Söding [10].

3.1 Inclusive Large $p_T$ Jet Cross Sections

Studying collisions of hadrons in which a large $p_T$ particle is produced it has been found that this particle is often accompanied by other secondaries emitted roughly in the same direction forming together a jet [11]. This may be seen in fig. 6 where the particle density is plotted in the region of rapidities and azimuthal angles close to the large $p_T$ hadron, called here a trigger particle [12]. Its position is indicated in the figure by the vertical arrow. The coordinates $\Delta y$ and $\Delta \phi$ are the rapidity and the angle measured with respect to the position of a large $p_T$ trigger. A distinct maximum peaking at this position is the manifestation of large $p_T$ jets.

A spectacular demonstration of jets produced with large transverse energy has been obtained last year at the CERN proton–antiproton collider [13,14]. When triggering the detectors with the large transverse energy deposition the UA2 and UA1 Collaborations found that most often the energy is concentrated in two limited regions of the longitudinal rapidity and the azimuthal angle. The two regions are

Fig. 6 – Density of particles emitted together with a large $p_T$ triggering hadron.
separated in azimuth by roughly 180°, as expected if the large transverse energy deposition is due to the scattered partons. The example of such a collision is shown in fig. 7 [13]. It shows two distinct jets, each carrying about 100 GeV transverse energy.

Similar examples of two-jet events have been also obtained at the CERN ISR by the CERN-Michigan State-Oxford-Rockefeller Collaboration as shown in fig. 8. In this case the detector has been triggered with the electromagnetic transverse energy only. The event displayed here shows a clear two-jet structure, however, the rate of such events at the ISR (\(\sqrt{s} = 63\ \text{GeV}\)) is much lower than that observed at the CERN \(p\bar{p}\) collider (\(\sqrt{s} = 540\ \text{GeV}\)). In fact, the increase by few orders of magnitude of the transverse jet cross section from the ISR to the \(p\bar{p}\) collider has been predicted by R. Horgan and M. Jacob [15]. The recent results confirm this prediction.

**Fig. 7** - Transverse energy distribution as a function of polar angle and azimuth for a \(p\bar{p}\) collision at \(\sqrt{s} = 540\ \text{GeV}\).

**Fig. 8** - Transverse energy distribution as a function of rapidity and azimuthal angle for a \(p\bar{p}\) collision at \(\sqrt{s} = 63\ \text{GeV}\).

The inclusive differential cross section for the jet production at \(\sqrt{s} = 540\ \text{GeV}\) has been measured as the function of a transverse jet energy by both the UA2 and UA1 Collaborations [16,17]. The results are shown in figs 9 and 10. They cover the range of the transverse energy from 20 to 110 GeV. Within this interval, the inclusive cross section falls by five orders of magnitude. We can notice that the experimental data roughly agree with the predicted values [15] shown in the figures as full lines.
Fig. 9 - Inclusive cross section for large transverse energy jets produced in pp collisions at \( \sqrt{s} = 540 \text{ GeV} \) as measured by the UA2 Collaboration.

Fig. 10 - Inclusive cross section for large transverse energy jets produced in pp collisions at \( \sqrt{s} = 540 \text{ GeV} \) as measured by the UA1 Collaboration.
The large transverse energy trigger used successfully to detect jets at \( \sqrt{s} = 540 \text{ GeV} \) has failed to do that at \( \sqrt{s} = 25 \text{ GeV} \) [18]. However, already at \( \sqrt{s} = 45 \text{ GeV} \) the Axial Field Spectrometer Collaboration has shown that this trigger can be used to measure the jet cross section [19]. The collaboration has used the ability of the detector to measure the momenta of individual secondary hadrons. This has allowed to characterize the event shape in the transverse momentum plane with a circularity parameter, \( C \). For each event, the momentum tensor made up of the transverse momenta of secondaries has been diagonalized and its eigenvalues \( A \) and \( B \) \((A > B)\) have been used to calculate \( C \):

\[
C = 1 - (A - B)/(A + B).
\]

![Graph](image)

The circularity \( C \) equals zero for two infinitely slim jets and equals one for the isotropic distribution of secondaries. The distribution of \( C \) for collisions with different transverse energy, \( E_T \), requirements are shown in Fig. 11 for \( \sqrt{s} = 63 \text{ GeV} \). At very high \( E_T \) values the concentration of events in the small \( C \) region is clearly seen, indicating the production of two transverse jets. Using a Monte-Carlo calculation the authors have been able to extract the two jet cross section shown in Fig. 12.

![Graph](image)

**Fig. 11** - Circularity distribution for pp collisions with various transverse energy triggers.

**Fig. 12** - Inclusive cross section for large \( p_T \) jets produced in pp collision at \( \sqrt{s} = 45 \text{ GeV} \) and 63 GeV. Both, statistical and systematic errors are shown.
Recently more calculations of the inclusive cross section for jets produced at the collider energy have been performed [20,21]. In order to do such calculations one has to take into account [20]:

- the quark and gluon structure functions of a nucleon,
- the scale breaking of the structure functions with $Q^2$,
- the influence of the intrinsic transverse momentum of partons before scattering,
- the contribution from higher order diagrams.

Different approaches to these problems give slightly different results. However, in general they reproduce the measured cross section within a factor 2–3 which is not very different from systematic uncertainties present in the data. The quoted overall systematic error of the UA2 results is 40% whereas the UA1 Collaboration estimates that systematic uncertainties may bring a factor of 1.65 to the measured cross section. As an example of the calculations of the jet inclusive cross sections, the results of N.G. Antoniou et al. [21] are shown in figs 9 and 10 as dashed lines. The authors used the same approach to calculate the jet cross section at collision energies 45, 63 and 540 GeV. The results obtained for two lower energies are confronted with the data of the Axial Field Spectrometer Collaboration in fig. 12. Comparing figs 9, 10 and 11 we can see that the variation of the jet cross section by a factor of 10? in the investigated range of the collision and transverse energies is well reproduced by the calculations.

We will end this section with a remark on the large $p_T$ hadron production on nuclear targets. It is known that nuclear effects enhance the yield of such hadrons. This increase is, usually, attributed to a multiple scattering of a secondary hadron (or parton) in nuclear matter. The RISK Collaboration has presented results supporting this conjecture [22]. As it is shown in fig. 13 the average number of protons ejected from a nucleus is bigger for collisions with a large $p_T$ hadron than that from average collisions.

![Average number of protons produced in $\pi^{-}$ nucleus collisions for average interactions (black points) and for interactions with a large $p_T$ hadrons (open circles).](image)

3.2 Nature of Scattered Partons

The results of the calculations of large $p_T$ jet cross sections reproduce reasonably well experimental values. This suggests strongly that the picture of a parton–parton scattering assumed to be a source of large $p_T$ jets reflects the physical reality. However, if it is true, many other consequences of the parton–parton scattering have to be found in experiments. In particular one has to be able to demonstrate that scattered partons are in fact quarks and gluons.
From the quark content of a proton we could expect that in the proton-proton collisions there should be twice as many scattered up quarks than down quarks. After scattering a quark fragments into a jet of hadrons. Sometimes it happens that most of the quark momentum is taken by a single hadron which contains the scattered quark. In this case an u quark will produce a large $p_T$, $\pi^+$ and a d quark will give a large $p_T$, $\pi^-$. Therefore, the quark composition of a proton leads to the prediction that the cross section to produce a large $p_T$, $\pi^+$ should be twice as large as that for a $\pi^-$. The Ames-Bologna-CERN-Dortmund-Heidelberg-Warsaw (ABCDHW) Collaboration has measured the inclusive cross sections for the production of positive and negative pions as a function of transverse momentum [23]. The ratio of two cross sections is shown in fig. 14. It reaches the value of two at large $p_T$ values as expected from the valence quark composition of colliding protons.

![Diagram](image)

**Fig. 14** - Ratio of the inclusive cross section for $\pi^+$ to that for $\pi^-$ produced in pp collisions at $\sqrt{s} = 63$ GeV.

A similar result has been obtained by the Axial Field Spectrometer Collaboration [24]. Fig. 15 shows the ratio of the density of positive jet fragments to that of negative ones as a function of the fraction of the jet momentum carried by a fragment, $x_p$. Again for large $x_p$ values the ratio is close to two.

Another consequence of the quark scattering is the value of the relative production of $K^+$ to $\pi^+$ mesons at large transverse momenta. According to the quark scattering picture both mesons originate from a scattered u quark. Their yields depend on probabilities to pick up a d or an s antiquark by the u quark. These probabilities do not depend on the scattering process and therefore the relative rate of the $K^+$ to $\pi^+$ production should not depend on the transverse momentum. The data of the ABCDHW [25] and the Axial Field Spectrometer [27] Collaborations shown in fig. 16 confirm this expectation.
The results discussed above indicate that in fact the scattered quarks contribute to the production of hadrons at large $p_T$. The analysis of the ABCDHW Collaboration has shown that the scattering of gluons is also present in this production [25]. The collaboration has investigated the $p$–$p$ collisions at $\sqrt{s} = 63$ GeV recorded with the Split Field Magnet detector. In addition to the large $p_T$ triggering $K^-$, other charged particles have been recorded over the 4\pi space angle. Neutral strange particle decays have also been detected. The produced large $p_T$ $K^-$ does not contain a valence quark of a proton. Therefore, it has to be produced via one of the following mechanisms:

- the scattering of a strange quark from the sea,

- the valence quark scattering with its subsequent fragmentation in such a way that the fastest hadron does not contain the scattered quark (rank reordering),

- the scattering of a gluon which then fragments into an $s$–$\bar{s}$ pair.

The strange sea quark scattering cannot be a dominant mechanism because of the following observation. Neutral kaons produced in events triggered by a large $p_T$ charged kaon are concentrated around its direction in contrast with neutral kaons associated with a large $p_T$ pion. This can be seen in fig. 17 where the rapidity distribution of a $K^0$ measured with respect to the rapidity of a triggering hadron is plotted. For $K^-$ events rapidities of neutral kaons are concentrated at the rapidity of a large $p_T$ kaon. This proves that both, $s$ and $\bar{s}$ quarks belong to the same large $p_T$ jet which, therefore, carries no strangeness.
Fig. 17 - Rapidity distribution of neutral kaons from pp collisions in which a large $p_T$ charged kaon or a pion was produced.

The second argument in favour of the gluonic origin of large $p_T$ $K^-$'s is the experimental observation that partons which fragment into $K^-$'s carry no electric charge. In Fig. 18 the densities of jet fragments which follow a large $p_T$ hadron are plotted versus their longitudinal momentum divided by the momentum of a triggering hadron.

Fig. 18 - Distribution of jet fragments associated with a large $p_T$ triggering hadron.
For large $p_T\pi^+$ events positive and negative jet fragments have similar distributions. In this case they are expected not to be very different as only 1/3 of the elementary charge unit brought to a leading $\pi^+$ by a $\bar{d}$ anti-quark has to be compensated. The rest of the $\pi^+$ charge is already contained in the scattered $u$ quark. In contrast to that, positive fragments associated with a large $p_TK^-$ follow much closer this leading negative particle than negative fragments. This may be expected if the scattered parton does not contribute to the electrical charge of a large $p_TK^-$. Therefore the charge of the $K^-$ has to be compensated by another fast positive jet fragment. This gives the observed excess of positive over negative fragments at large longitudinal momenta.

Experiments show that quarks and gluons are not the only partons contributing to the large $p_T$ hadronic production. The ABCDHW Collaboration has measured the relative yields of protons and antiprotons with respect to all hadrons of the same charge produced in p-p collisions at $\sqrt{s} = 63$ GeV [26]. The measurements have been performed at 10°, 20° and 45° polar angles. The AFM Collaboration has measured these yields at 90° [27]. The results of both collaborations are shown in fig. 19 which demonstrates a strong angular dependence of the relative proton yield.

If the production of protons were due to the fragmentation of scattered quarks and gluons, their relative rate should not depend on the emission angle because the fragmentation of a parton does not depend on the scattering process. On the other hand the scattering of diquarks should contribute mainly to the small polar angle region due to the form factor of a diquark. This is supported by experimental data shown in fig. 19 which show a decrease of the relative proton yield with the increasing polar angle.

In conclusion the data presented in this section have shown that the scattering of quarks and gluons is responsible for the production of large $p_T$ hadronic jets. In addition, the scattering of diquarks contributes to the production of jets which fragment into large $p_T$ protons.
3.3 The Mechanism of the Parton-Parton Scattering

The simple picture of the scattering of quarks and gluons assumes that it is dominated by the exchange of a single vector gluon. Experimental evidences supporting this picture have been already given at $\sqrt{s} = 63$ GeV [28,29]. The results of the UA1 [17] and UA2 [16] Collaborations presented at this conference have demonstrated that the vector gluon exchange is responsible for the production of large transverse energy jets also at the collider energy, $\sqrt{s} = 540$ GeV. Two large $E_T$ jet collisions in which the energies and directions of both jets have been measured allowed to calculate the parton scattering angle in the parton-parton c.m.s., $\theta^*$. The distributions of $\cos \theta^*$ obtained by the UA1 and UA2 Collaborations are plotted in figs 20 and 21 respectively.

The wide rapidity acceptance of the UA1 detector has allowed to extend the measured $\cos \theta^*$ region up to 0.8. As we can see in fig. 20 the data exclude a scalar gluon exchange and are in an excellent agreement with a single vector gluon mechanism.

**Fig. 20** - Angular distribution of scattered partons in their rest frame measured by the UA1 Collaboration in pp collisions at $\sqrt{s} = 540$ GeV. Expectations for the scalar (dashed lines) and the vector (full lines) gluon exchange are also shown.

**Fig. 21** - Angular distribution of scattered partons in parton-parton c.m.s. obtained from two-jet pp collisions at $\sqrt{s} = 540$ GeV.
3.4 Some Aspects of the Jet Fragmentation

The review of the properties of jets, also of those produced in hadronic collisions, has been presented by P. Söding [10]. In this section we will discuss only selected aspects of the jet fragmentation. For more details the reader is referred to [10].

The first problem we will consider here is the total multiplicity of charged secondaries, \( \langle n \rangle \), produced in association with a large \( p_T \) hadron. The data of the ABCDHW Collaboration recorded with the Split Field Magnet detector are shown in fig. 22 for collision energies 45 and 63 GeV [30]. The average multiplicity increases with the transverse momentum of a triggering hadron and then levels off at \( p_T \approx 3 \text{ GeV/c} \). For collisions at \( \sqrt{s} = 63 \text{ GeV} \) the multiplicity increases from \( \sim 14 \) for average inelastic interactions to \( \sim 18 \) for interactions in which a hadron with a transverse momentum larger than 3 GeV/c is produced. In contrast to the increase of \( \langle n \rangle \), the dispersion of the charged multiplicity distribution, \( D \), decreases from 6.1 to 5.5.

Fig. 22 - The average charged particle multiplicity and the dispersion of the multiplicity distributions for pp collisions with a large \( p_T \) particle produced as a function of \( p_T \).

For soft proton-proton collisions the dispersion and the average charged multiplicity are related by a linear dependence [31] as shown in fig. 23 [32]. The point for collisions at \( \sqrt{s} = 63 \text{ GeV} \) associated with a large \( p_T \) hadron is also shown in the figure. It falls much below the general \( \langle n \rangle - D \) dependence. The dispersion of the multiplicity distribution for large \( p_T \) collisions is significantly smaller than that for average collisions with the same value of \( \langle n \rangle \). A possible explanation of this observation is that charged particles in a large \( p_T \) collision come from the independent fragmentation of more than one hadronic system. For instance, if two independent fragmentations, each with \( \langle n \rangle = 9 \), are combined to create one large \( p_T \) event with \( \langle n \rangle = 18 \), the dispersion should be equal to that expected for \( \langle n \rangle = 9 \) multiplied by \( \sqrt{2} \).
This will give $D = \sqrt{2} \cdot 4.8 = 6.8$, the value close to that observed for large $p_T$ collisions. We can conclude therefore, that in a p-p collision with a large $p_T$ hadron, secondary particles origin from at least two systems which fragment independently.

![Graph](image)

**Fig. 23** - The dispersion of the multiplicity distributions of charged secondaries produced in pp collisions plotted versus the average multiplicity. The corresponding point for collisions with a large $p_T$ hadron is also shown (x).

However, it is not known what may be the fragmenting systems. Hadronic collisions with two large $p_T$ jets produced are in fact a four jet object [33]. This may be seen in fig. 24 where the momentum flow in the four jet plane is plotted [34]. There are two transverse jets, T1 and T2 and two spectator jets, S1 and S2. Usually it is believed that jets T1 and T2 form a fragmenting system which is often used to compare high $p_T$ jets with those from $e^+e^-$ collisions.

However, if a colour gluon is exchanged in the parton scattering it is rather the S1-T1 (and S2-T2) system which fragments. Also a more complicated structure of the fragmentation may occur.

In order to look for possibilities to investigate the fragmentation in large $p_T$ hadronic collisions, the generated density of fragments is plotted in fig. 25. In the generation the density of fragments was assumed to be constant along the rapidity axis in the jet-jet c.m.s. It was also assumed to fall exponentially with transverse momentum defined with respect to this axis. Fig. 25(a) shows the density of fragments from the T1-S1 and T2-S2 systems, whereas in fig. 25(b) the density of fragments from the T1-T2 and S1-S2 systems is plotted. Two coordinates are the rapidity in p-p c.m.s., $y$ and the transverse momentum component in the four jet plane, $p_x$. 
Fig. 24 — The four-jet structure of the pp collisions with two large \( p_T \) hadrons produced. The momentum flow of particles produced in addition to large \( p_T \) hadrons is plotted in the four-jet plane.

It can be noticed from fig. 24 that the average rapidity of transverse jet fragments emitted with the largest \( p_T \) is slightly different than the average rapidity of fragments with lower \( p_T \). This difference is due to the Lorentz transformation from the jet-jet rest frame to the centre of mass system of two colliding protons. We can expect, therefore, a systematic shift between the direction of a large \( p_T \) triggering hadron and the direction of remaining particles in the transverse jet. For two cases displayed in figs. 24(a) and 24(b) the expected shifts have opposite signs. Such a difference between two directions has been found experimentally by the ABCDHW Collaboration [12]. It is shown in fig. 26 where the angle between the momentum of a large \( p_T \) particle and the jet momentum is plotted as a function of \( p_T \). More studies are needed to understand the meaning of this effect. Nevertheless, it indicates a possibility to disentangle different fragmentation systems.
Fig. 25 - Particle density as a function of rapidity and transverse momentum component in the four-jet plane. (a) For fragments of T1-S1 and T2-S2 systems. (b) For fragments of T1-T2 and S1-S2 systems.

Fig. 26 - The angle between the momentum a large $p_T$ hadron and the momentum of the entire jet plotted versus hadron transverse momentum.

4. CONCLUSIONS

We can conclude the large transverse momentum part of this review with the following remarks:

- New, often very spectacular and important experimental results on global characteristics and on the detailed structure of large $p_T$ collisions have been presented to this conference.

- Experiments have covered the collision energy range from 20 to 540 GeV and the transverse momentum (energy) range up to 120 GeV/c.
- Theoretical calculations reproduce the experimental inclusive cross sections within a factor 2-3. This supports the quark parton model of large $p_T$ collisions.

- The quark parton model is also supported by more detailed experimental results on the structure of large $p_T$ collisions.
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