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Transverse Momentum Effects and Angular Energy Flow in Leptoproduction

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Abstract:

We show that with the inclusion of soft gluon emission the experimental p_t-spectra of leptoproduced hadrons is well reproduced without having an unphysically large primordial transverse momentum. A way to distinguish experimentally between primordial and soft gluon effects is given.

We further show that the forward-backward asymmetry in the hadronic energy flow predicted by perturbative QCD is, at presently available energies, difficult to observe in the final state of observable particles due to the fragmentation of the jets. The decay of unstable particles produces an energy flow at large angles which washes out the QCD parton level asymmetry. Kinematical effects from the production of a baryon in the target fragmentation jet will, however, give rise to a forward-backward asymmetry that is larger than the QCD asymmetry at present energies.

1. Introduction

In previous papers [1,2] we have studied high energy leptoproduction using a model where perturbative QCD is used to give the cross sections to order α_s and the Lund jet model [3] is used for the soft hadronization process. The resulting model is implemented in terms of a Monte Carlo program [4] which simulates complete events.

In this paper we continue the studies of the transverse momentum spectra of the hadronic system. There are several contributing sources to the transverse momentum (with respect to the momentum direction, $\bar{Q}$, of the virtual photon) of the final state hadrons:

I. In the soft fragmentation process quark-antiquark pairs are produced with a certain p_t in the colour force field. In a field without transverse excitations the quark and antiquark obtain equal but opposite p_t. This is given by a Gaussian distribution with $\langle p_t^2 \rangle = (0.44\ \mathrm{GeV/c})^2$.

II. First order QCD processes give rise to 3-jet events (i.e. events with 3 jets in the cms or 2 jets in the lab system) at a rate given by α_s. The partons themselves then obtain p_t which essentially depend on the total hadronic mass W [5].

III. There is also some transverse motion within the target proton, the so-called primordial transverse momentum k_t, of the parton struck by the virtual photon.

IV. Gluons which are too soft to give rise to separate jets of particles can still have effects on the p_t of the hadrons and give a recoil to the leading quark in an ordinary 2-jet event.

If only the first three contributions are included, many of the observable features can be well reproduced. However, it is necessary to make use of a primordial transverse momentum which is too large to be understood as a pure Fermi motion within the target proton. Furthermore different values of k_t are obtained when different physical quantities are studied. In this paper we show that these problems are resolved if also the fourth contribution is taken into account.

In order to test perturbative QCD there has been a great interest in properties which are insensitive to the hadronization process. The angular energy flow would have this property if the p_t effects arising in the hadronization process are sufficiently small to be neglected. It has been shown [6] that QCD gives a characteristic forward-backward asymmetry at the parton level. Since the amount of 3-jet events is proportional to α_s it has furthermore been suggested that this energy flow could, in particular, be used as a measure of α_s in leptoproduction experiments. We will, however, show that the corrections from the hadronization are, unfortunately, very large at the presently available energies. The production of unstable particles (e.g. vector mesons) results in decay products at large angles. Therefore the dominating 2-jet events wash out the asymmetry obtained in QCD. In fact, in our model, the dominating part of the observable asymmetry arises from the production of a baryon in the target fragmentation region.

2. Transverse momentum effects from soft gluons

When using first order QCD matrix elements one has to make cuts against the singularities for soft and collinear gluons. These gluons do not give rise to separate jets of particles and thus lead effectively to 2-jet situations. In the Lund model the colour force field is treated like a string spanned between the colour charges and stretched from the quark via the gluon to the target remnant. Thus we do not have three jets fragmenting independently of each other. It is rather these stringlike force fields which break up, fragment into hadrons. This provides a natural cut off for the divergencies [1,4]. For example, for a collinear gluon the energy in the field between the gluon and the quark is too small to produce quark-antiquark pairs. Thus the leading hadron will contain energy associated with both the quark and the gluon thereby resulting in a 2-jet configuration.

However gluons, which are too soft to give a jet of hadrons can still make a slight bend on the colour force field. As discussed in [7] (which treats the case of e^+e^- annihilation) this gives some extra p_t to the hadrons with rapidity close to the gluon rapidity and also a recoil to the leading quark. Hence, if the width of the fragmentation p_t is determined from experimental data, somewhat different values would be obtained depending on whether soft gluon effects are explicitly taken into account or not. The effects of varying the fragmentation p_t as implied by the soft gluon contribution are however rather small. In this paper we have hence chosen to keep it fixed.

For the 3-jet events the p_t distribution for the leading quark is a smooth function above a cut off value P, were P is essentially half the invariant mass M_{qg} discussed in section 3.1. Without the soft gluons the 2-jet events would correspond to a δ-function at $p_t = 0$. The inclusion of the soft gluon effects implies that the leading quark in a 2-jet event will get a p_t so that the hole in the distribution between 0 and P is filled up. When summing 2- and 3-jet events the p_t-distribution for the leading quark is now a smooth function from 0 and upwards. The result for the final state hadrons is unsensitive to a change in the cut off P. Such a change will only imply that some events are moved from the class of 3-jet events to the class of 2-jet events. We note that by using different cuts one can get somewhat different fractions of 3-jet events, although the fraction of events with a visible 3-jet structure is the same.

The recoil given to the leading quark results in a p_t for the fast hadrons which is proportional to the energy fraction z. This effect is rather similar to the effect from a primordial k_t. Such a k_t carried by the struck quark is balanced by an opposite k_t carried by the target remnants. This implies that the jet axis in the cms will be rotated slightly. Thus the hadrons get p_t-contributions proportional to x_F. The difference is that while for the soft gluon effect the p_t of a fast hadron is balanced in the whole central plateau, for the primordial k_t it is balanced in the target fragmentation region.

Starting from the first order QCD matrix elements [5] for leptoproduction one arrives, for soft gluons, at the same relevant equations as in e^+e^- [7], in particular;

$$\frac{1}{\sigma_0}\cdot\frac{d^2\sigma}{dp_t^2dy} \simeq \frac{4}{3}\cdot\frac{\alpha_s}{\pi}\cdot\frac{1}{p_t^2} \qquad (1)$$

Hence we apply the same method for treating soft gluons as described therein. For the case of a collinear gluon both the gluon and the leading quark will enter the same leading hadron which implies negligible effects on p_t. Thus the rapidity range over which we sum soft gluons is effectively only $\approx \ln(W^2/M^2)$ independently of the gluon p_t. A difference is that whereas in e^+e^- annihilation the gluon cannot unambigouosly be associated to the quark or the antiquark, in leptoproduction the p_t-recoil is always taken by the struck quark. Therefore, if p_t is measured with respect to the current direction, the p_t-recoil is carried by the leading quark in the current fragmentation region and not by the target remnants, also if the gluon is emitted backwards in the hadronic cms. However, if p_t is measured with respect to the thrust axis the situation is rather symmetric as indicated by eq. (1).

The scale for both soft and hard gluon emission is of course set by the strong coupling constant

$$\alpha_s(Q^2) = \frac{12\,\pi}{25\,\ln(Q^2/\Lambda^2)} \qquad (2)$$

For the Λ-parameter we have used the value 0.3 GeV. For this process a larger value of Λ than the one obtained from scaling violations of the structure functions, is expected. If, instead of the Q^2 of the virtual photon, we use the momentum squared of the intermediate off shell quark (this can easily be done for the hard gluon case) we have found that a smaller value of Λ can be used to reproduce the data. Throughout this paper we have taken α_s to be given by eq. (2) for both soft and hard gluon emission even though one could, in principle, use different Q^2 or Λ values.

In figs. 1 and 2 we show the resulting p_t spectra corresponding to 280 GeV muon-proton events having cuts similar to those used by the EMC, namely: $20 < \nu < 260$ GeV, $W^2 > 40$ GeV^2 and $Q^2 > 5$

GeV^2. As can be seen it is now possible to reproduce the data from the EMC collaboration [8] quite well having a more realistic value of the primordial transverse momentum corresponding to a Fermi motion within the target proton. We have here chosen a Gaussian k_t distribution having the same width as for the fragmentation p_t, giving $\langle k_t^2 \rangle$ = (0.44 GeV/c)^2. From fig. 1 it is clear that particles with a large energy fraction, $z=E_h/\nu$, are very sensitive to p_t from these two sources. The p_t-spectra for such particles, having $z > 0.7$, are given in fig. 3a which shows that a small k_t plus soft gluon effects give a very good agreement with data [8]. Also the distributions in $p_{t,in}^2$ and $p_{t,out}^2$ from the EMC collaboration [8] are well reproduced (in and out is here with respect to an event plane obtained by minimizing the sum of $p_{t,out}^2$). Before the soft gluon effects were introduced it was found [8] that in order to reproduce single particle p_t-spectra a larger k_t was needed than when reproducing collective p_t properties in an event, such as sums of p_t or energy flow. When including these effects, however, we have found that the same value can be used to reproduce both kinds of data. As an example we show in fig. 3b the distribution of the squared sum of $\bar{p}_t$ in the events. We want to point out that we have not made a fit to the data but rather taken the attitude to choose realistic values of the parameters and then compare the results with the experimental data. A fine tuning of the parameters in the model may improve the agreement slightly.

To test more directly the soft gluon effects we suggest a study of the p_t-balance of a trigger particle with high z. As mentioned above the main difference between the primordial k_t and the soft gluon effect is that in the first case the p_t is balanced in the target fragmentation region while in the second case it is balanced in the central plateau. This is seen in fig. 4 which shows how the p_t-compensation by the remaining particles in the event is distributed in pseudorapidity. There is a clear difference in the target fragmentation region which can be studied in the next generation of muon experiments. Due to the large number of particles in the central region it ought to be possible to get a precise value for the mean p_t in this region already in current experiments.

3. Angular energy flow in the hadronic cms

3.1. Energy flow at the parton level

Let us start by considering the QCD predictions on the parton level. The QCD result diverges in the forward and backward directions and it is necessary to introduce some kind of cuts. In the Lund model these cuts are expressed in terms of requirements on the invariant masses M_{qg}, $M_{\bar{q}g}$ and $M_{q\bar{q}}$; here M_{qg} is the mass of the quark-gluon system etc. (the target jet, being a colour antitriplet, is here symbolized by an antiquark). Gluons which are too soft for these cuts are taken into account by the soft gluon effects on the 2-jet events as described above. However, we have checked that our results do not depend on the details of the Lund fragmentation model by comparing with a model where the three jets are considered to go out from the origin in the center of mass system and fragment independently of each other. In this case we follow a cut procedure à la Sterman and Weinberg [9], i.e. require for a bona fide 3-jet event that a certain energy is outside a double cone with a given opening angle around the current direction.

There are different ways one can think of to normalize the differential energy flow. From a theorist's point of view it may be natural to normalize to the total integrated energy flow outside a specified Sterman-Weinberg cone. At the parton level only 3-jet events would then contribute. If, however, also 2-jet events can produce final particles at large angles this normalization is not convenient when comparing with experimental data. For the experimentalist it is difficult to obtain a pure sample of unbiased 3-jet events and it is more natural to normalize to the total integrated energy of all events, i.e. both 2- and 3-jet events, and to cover the total angular region. This is also the normalization we have used.

The dashed curve in fig. 5 exhibits the resulting angular distribution of energy flow at the parton level for the 3-jet events in 280 GeV muon-proton interactions, simulated according to the differential cross section formula and with some convenient experimental cuts on the kinematic variables: $Q^2 > 5$ GeV^2, $20 < \nu < 260$ GeV and $W^2 > 5$ GeV^2. The dip around $\cos(\theta) = -0.8$ is not due to the QCD matrix elements, but a result of the specific cuts in the string model applied at these relatively low center of mass energies. If a primordial transverse momentum of the partons in the target proton is introduced the curve will rise near $\cos(\theta) = -1$ since also the target jet can then have an angle with respect to the current direction. The dash-dotted curve in fig. 5 shows the parton level result for the "independent jet" type model.

3.2. Influence of the hadronization process

Let us now consider the influence of the soft fragmentation. We first study the effect caused by the decay of unstable particles, e.g. vector mesons. Therefore we assume that there is neither any primordial transverse momentum nor any transverse momentum introduced in the primary fragmentation process, i.e. in the break up of the colour field. So far, we do not include effects from soft gluons or the target baryon effect but approximate the diquark in the target fragmentation jet with an antiquark which is also a colour antitriplet. The resulting energy flow is shown by the dotted curve and does not show any QCD asymmetry. We note that the energy flow is also much larger in this case and conclude that the effect is due to the fact that also some 2-jet events can produce particles at large angles to the current direction. The large number of 2-jet events will then completely mask the asymmetry that was produced by the 3-jet events. When the primordial and fragmentation transverse momentum is also taken into account (the former only gives a very small effect) the result is given by the full line in fig. 5. The "independent jet" model gives the same curves on the hadronic level.

When using different cuts the resulting energy flow at the parton level might vary somewhat. Very weak cuts will produce jet configurations that are not possible to project onto

physical final states due to mass effects. At the particle level, however, the same distribution should emerge. This is also what we find.

Before continuing let us, as a convenient and more sensitive measure of the forward-backward asymmetry, define the quantity

$$A = \frac{E(\theta) - E(\pi-\theta)}{E(\theta) + E(\pi-\theta)} \qquad 0 < \theta < 90 \qquad (3)$$

where E is the energy flow at a certain angle θ in the cms. The dotted lines in fig. 6 show this asymmetry when the only source of asymmetry is hard QCD corrections to first order as discussed so far. When taking into account that the leading quark can radiate soft gluons and thereby obtain a recoil, as discussed in section 2, it is clear that some forward-backward asymmetry will be produced. The size of this effect when added to the hard processes is shown by the dashed lines in fig. 6.

3.3. Target jet fragmentation

The fragmentation of the diquark in the target jet has been treated as described in our earlier paper [2]. As it turns out, the largest source of asymmetry at the particle level are the effects from producing a baryon from this diquark in the target fragmentation jet. The result, which is given by the full line in fig. 6b, is essentially caused by the fact that a leading baryon, in general, takes a larger fraction of the jet energy than a meson does. This also results in a somewhat lower multiplicity in the backward jet. The larger energy fraction for the baryon is partly due to pure mass effects but depends also on the model for the diquark fragmentation. In the Lund model the diquark in the target fragmentation jet is assumed to stretch a colour field in a stepwise manner, resulting in a colour flux tube similar to the one in the current fragmentation region. This flux tube is cut into pieces by the production of new quark-antiquark pairs. The first rank hadron can contain either one or both of the initial quarks in the diquark, thus forming either a meson or a baryon. To first approximation the total hadron spectrum (including both baryons and mesons) is the same for a diquark and a quark jet. However a small difference is introduced from the fact that a baryon must be a symmetric state of three quarks. This favours slightly the case when both original quarks, which are already in a symmetric state, go into the baryon. This will favour a larger energy fraction to be given to the baryon. For a more detailed description of this fragmentation process we refer to [2].

This effect is slightly enhanced by the different behaviour in the decay of unstable baryons and mesons. In baryon decay most of the parent momentum is taken by the daughter baryon which will go in more or less the same direction as its parent. In the more symmetric meson decay the daughter mesons carries off more energy at large angles from the parent particle momentum.

Another contributing source is that the emission of soft gluons by the leading quark will soften the z-spectrum more in the forward jet than in the backward jet [7].

In conclusion, the largest part of the energy flow asymmetry in an inclusive event sample is not due to QCD effects, but is a result of baryon production in the target fragmentation jet. The magnitude seems to be of the correct order when comparing with recent neutrino results on the energy flow from the Fermilab 15-foot bubble chamber [10].

3.4. Ways to observe the QCD asymmetry

Using trigger conditions, e.g. a high p_t trigger as discussed in [1], it is possible to get a set of events with a substantially increased fraction of 3-jet events. Such a subset can show QCD properties more clearly. The assumed hadronization independence of the energy flow is, however, lost by requiring a specific particle property. Such a trigger may also introduce biases resulting in an asymmetry from ordinary 2-jet events even if no QCD or baryon effects exist, even though the trigger rate would be much smaller. The trigger condition should, of course, be forward-backward symmetric in itself and we have for fig. 7 simply required a trigger particle having $p_t > 1.25$ GeV/c. As can be seen, the particle level result is here

showing more of the parton level QCD features.

At larger energies the hadronization effects described above should become less important. We have checked that even for a 750 GeV muon beam the QCD asymmetry is not directly observable. At this energy it should, however, be easier to get a good sample of 3-jet events using cuts or trigger conditions. As an indication of the situation at still higher energies we have extrapolated our model to the planned ep collider energies [11]. We have chosen the configuration planned for CHEER, the Canadian collider project, i.e. 10 GeV electrons on 1000 GeV protons. As can be seen in fig. 8 the predicted QCD asymmetry should be seen directly in the distribution of the final state particles. It should be noted, however, that our extrapolation does not include second or higher order QCD corrections. If one goes into an investigation of what subprocess (ordinary 2-jet, gluon bremsstrahlung or photon-gluon fusion) which dominates at these extreme momentum tranfers, the choice of structure functions is essential. We have in this work used the parametrizations by Glück, Hoffmann and Reya [12].

4. Conclusions

We have demonstrated that by taking soft gluon emission into account the transverse momentum properties of the final state hadrons can be well reproduced without the need for an unphysically large primordial transverse momentum k_t of the partons within the target nucleon. The same value of k_t can be used to reproduce different physical quantities, in particular both single particle spectra and collective properties in an event.

We have also pointed out an experimentally testable difference between soft gluon effects and a large primordial transverse momentum by studying the p_t-balance within the events.

The asymmetry in the angular energy flow, as predicted by QCD, is hard to observe experimentally since it is washed out in the soft hadronization process. We note that at present energies the leading baryon in the target fragmentation region causes the largest part of the observable asymmetry. Therefore the energy flow is, unfortunately, not a hadronization independent test of QCD at the presently available energies.

References:

1. B. Andersson, G. Gustafson, G. Ingelman, T. Sjöstrand: Z. Physik C9 (1981) 233

2. B. Andersson, G. Gustafson, G. Ingelman, T. Sjöstrand: Baryon production in lepton-nucleon scattering and diquark fragmentation, Lund preprint LU TP 81-6

3. B. Andersson, G. Gustafson, C. Peterson : Z. Phys. C1 (1979) 105
B. Andersson, G. Gustafson : Z. Phys. C3 (1980) 22
B. Andersson, G. Gustafson, T. Sjöstrand : Z. Phys. C6 (1980) 235

4. G. Ingelman, T. Sjöstrand: A Monte Carlo program for leptoproduction, Lund preprint LU TP 80-12.
T. Sjöstrand : A Monte Carlo program for quark and gluon jet generation, Lund preprint LU TP 80-3.

5. G. Altarelli, G. Martinelli: Phys. Lett. 76B (1978) 89

6. E.K. Manesis, N.A. Papadopoulos: Phys Lett 86B(1979)361
E.K. Manesis, N.A. Papadopoulos: Nucl Phys B174(1980)300
E.K. Manesis, N.A. Papadopoulos: QCD and hadronic energy flow at SPS and HERA energies, Johannes Gutenberg Universität, Mainz preprint MZ-TH 80/7.
F. Halzen, D.M. Scott in Proceedings of the XI:th International Symposium on Multiparticle Dynamics, Brugge, Belgium (1980).

7. B. Andersson, G. Gustafson, T. Sjöstrand: On soft gluon emission and the transverse momentum properties of final state particles, Lund preprint LU TP 81-4, to be published in Z. Physik C.

8. European Muon Collaboration
J.J. Aubert et al.: Phys. Lett. 95B (1980) 306
J.J. Aubert et al.: Phys. Lett. 100B (1981) 433
J. Gayler: DESY preprint 81-063

9. G. Sterman, S. Weinberg: Phys. Rev. Lett. 39 (1977) 1436

10. H.C. Ballagh et al.: Phys. Rev. Lett. 47 (1981) 556

11. G. Ingelman : CHEER Monte Carlo based on the Lund jet model - program manual.

12. M. Glück, E. Hoffmann, E. Reya : Scaling violations and the gluon distribution of the nucleon, Dortmund preprint DO-TH 80/13.

13. ABCDLOS-collaboration: preprint CERN-EP/80-66

Figure captions:

Fig. 1 The mean squared transverse momentum as a function of z^2. The curves show the contribution from: I: the fragmentation process as described by our cascade model, II: first order QCD processes, III: primordial transverse momentum, $\langle k_t^2 \rangle = (0.44\ \mathrm{GeV/c})^2$, IV: soft gluons, V: our model when all contributions are included. It should be noted that the p_t broadening coming from the decay of unstable particles is included in each of the curves, and hence there is some double counting between I, II, III and IV. In fact, the p_t broadening coming from decays is a minor effect, but decays must be included to give the correct z spectrum. The data points are from EMC [8].

Fig. 2 The mean squared transverse momentum for different z-bins is shown as a function of the squared cms hadron energy W^2 together with data from EMC [8] and ABCDLOS [13]. The full lines include soft gluon emission and have $\langle k_t^2 \rangle = (0.44\ \mathrm{GeV/c})^2$. For comparison our old curves (dashed) not including soft gluons and with $\langle k_t^2 \rangle = (0.8\ \mathrm{GeV/c})^2$ are also included.

Fig. 3 In (a) the p_t^2-spectrum for single particles carrying a large energy fraction, $z>0.7$, is given and in (b) the distribution of the squared $\bar{p}_t$-sum for events where the accepted tracks carry more than 70% of the total energy. The results of the model, including soft gluons emission and with $\langle k_t^2 \rangle = (0.44\ \mathrm{GeV/c})^2$, are compared with preliminary EMC data [8].

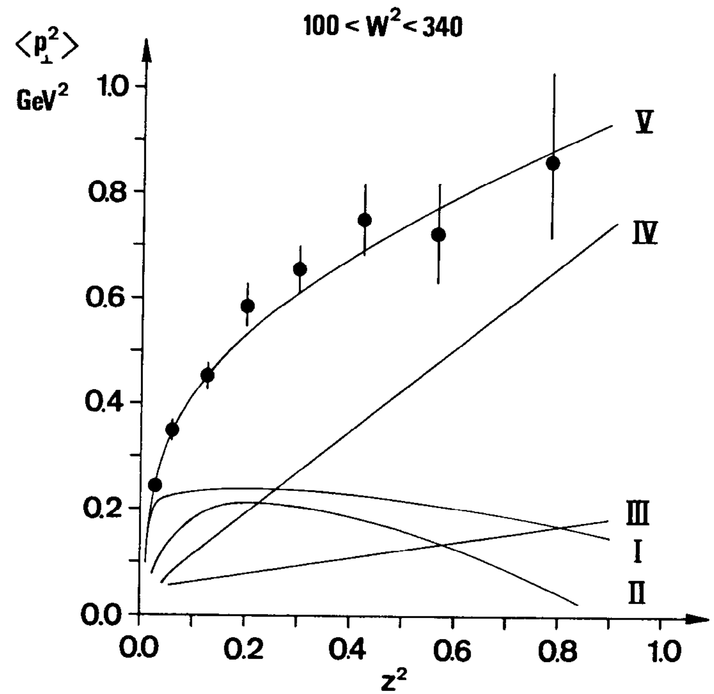
Fig. 4 The compensation of the transverse momentum of a fast trigger particle, having $z > 0.5$, by the remaining particles in the event as a function of pseudo-rapidity in the lab-system. The p_t is measured in a plane spanned by the trigger particle and the virtual photon. A true primordial k_t is compensated in the target fragmentation region, dashed line, whereas for soft gluons it is compensated in the central plateau, full line. The mean k_t for the two cases are as in fig. 2.

Fig. 5 Differential angular energy flow obtained by the Lund model for 280 GeV muon-proton interactions with the cuts $Q^2 > 5\ \mathrm{GeV}^2$, $W^2 > 5\ \mathrm{GeV}^2$ and $20 < \nu < 260$ GeV. The dashed curve is at the parton level, the dotted/full line is at the particle level excluding/including primordial and fragmentation transverse momentum. The dash-dotted curve is the result at the parton level for a model with jets fragmenting independently of each other. At the particle level this model gives the same result as the Lund model.

Fig. 6 The forward-backward energy flow asymmetry, as defined in eq. (3), in the hadronic center of mass system at the parton level (a) and particle level (b). The dotted lines give the result of hard QCD processes to first order, dashed lines also include effects from soft gluon emission. The full line shows the resulting asymmetry when also the production of a baryon in the target fragmentation jet is taken into account. The simulated events have the same kinematical constraints as in fig. 5.

Fig. 7 Energy flow asymmetry obtained by using a high p_t trigger, i.e. requiring a particle with $p_t > 1.25$ GeV/c. The dashed line is for the parton level and the full line is for the particle level. Primordial and fragmentation transverse momentum is included together with soft gluon and target baryon effects. The dotted line is the particle level result if QCD is switched off.

Fig. 8 Expected energy flow asymmetry at collider energies, here chosen as 10 GeV electrons on 1000 GeV protons, with the cuts $Q^2 > 1000\ \mathrm{GeV}^2$ and $W^2 > 100\ \mathrm{GeV}^2$. The dashed/full line is for parton/particle level respectively. The dotted line gives the contribution from first order, hard QCD processes to the result at the particle level.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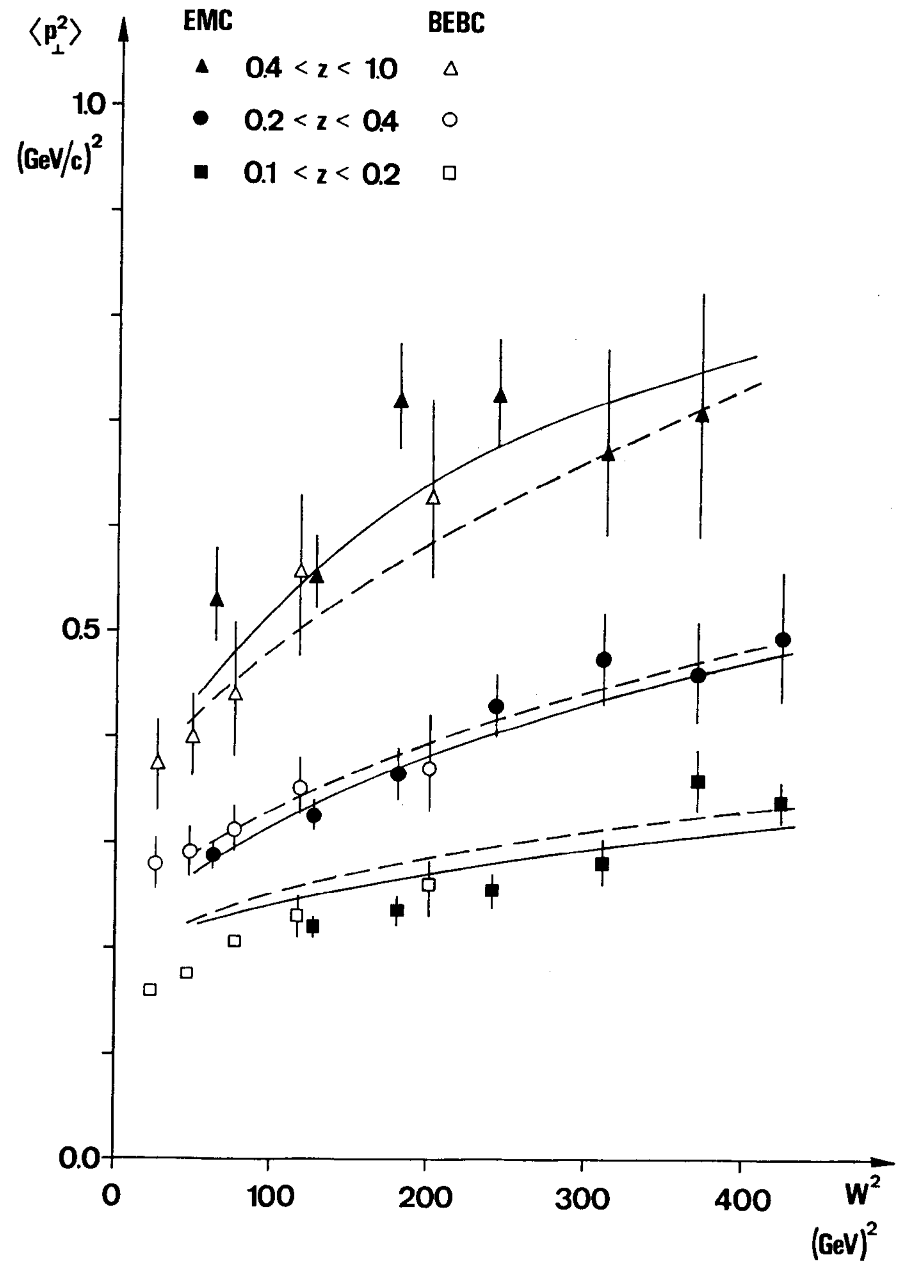
1.0
z^2

Fig. 1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(GeV/c)^2
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EMC
BEBC
$0.4 < z < 1.0$
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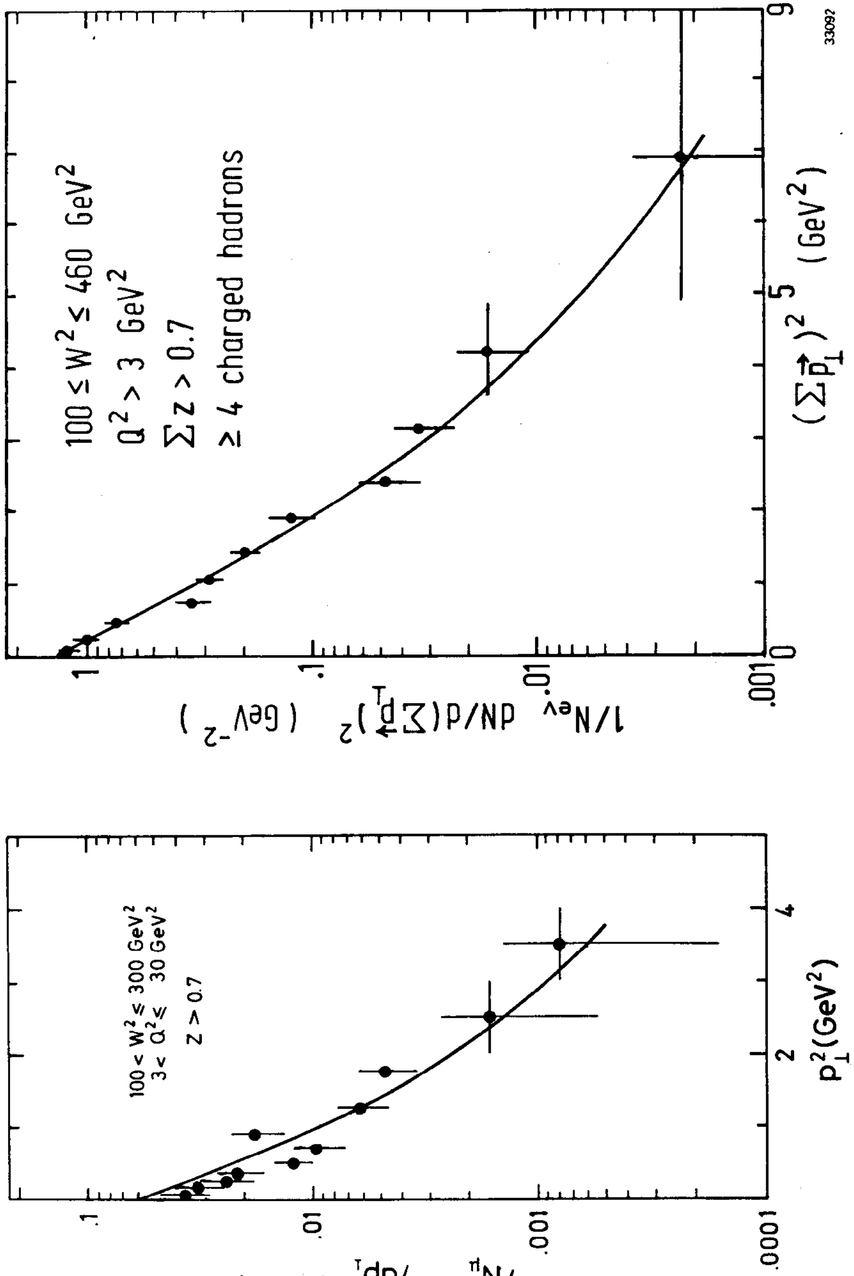
W^2
(GeV)^2

Fig. 2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Q² > 3 GeV²
Σ z > 0.7
≥ 4 charged hadrons
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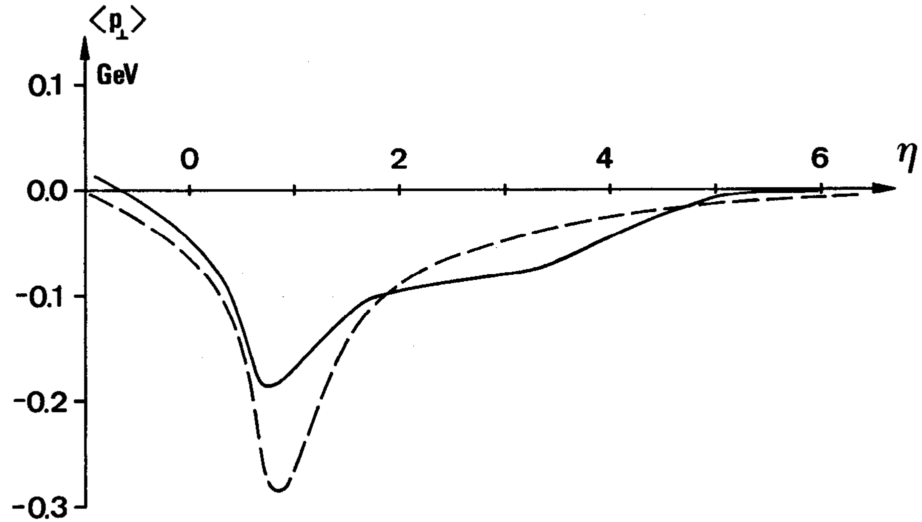
33092

a) b)

Fig. 3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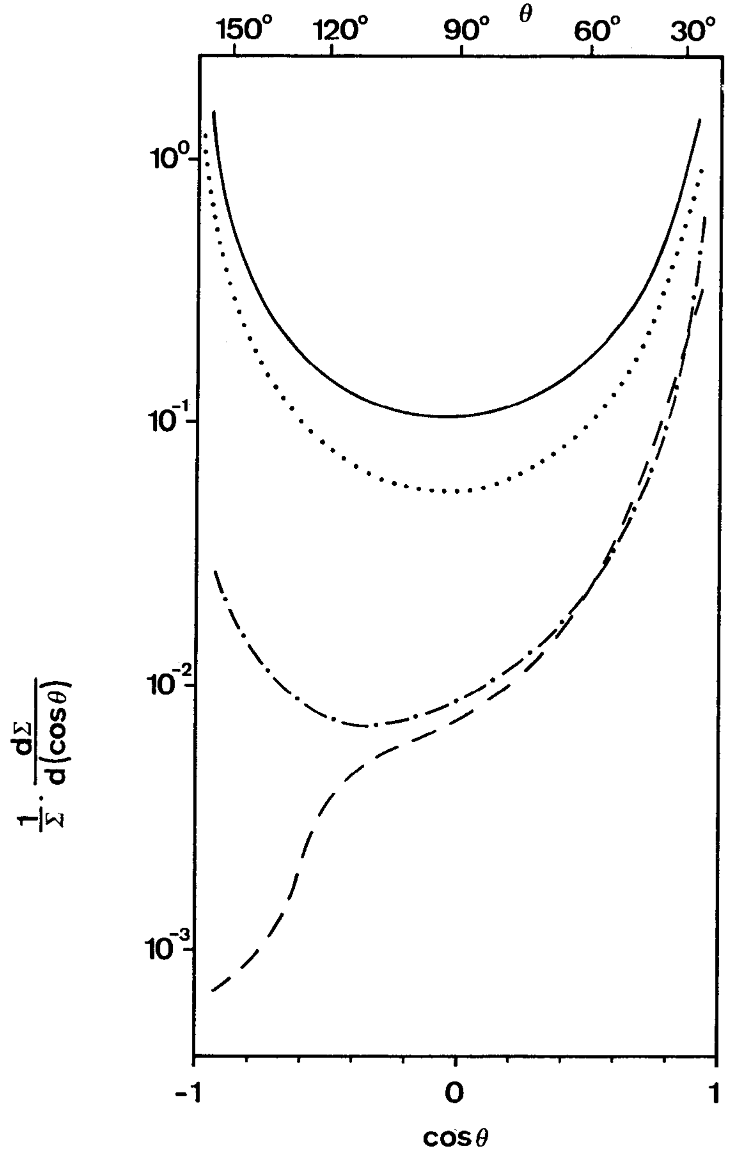
η

Fig. 4



150°
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90°
θ
60°
30°
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10^{-1}
10^{-2}
10^{-3}
$\frac{1}{\Sigma} \cdot \frac{d\Sigma}{d(\cos\theta)}$
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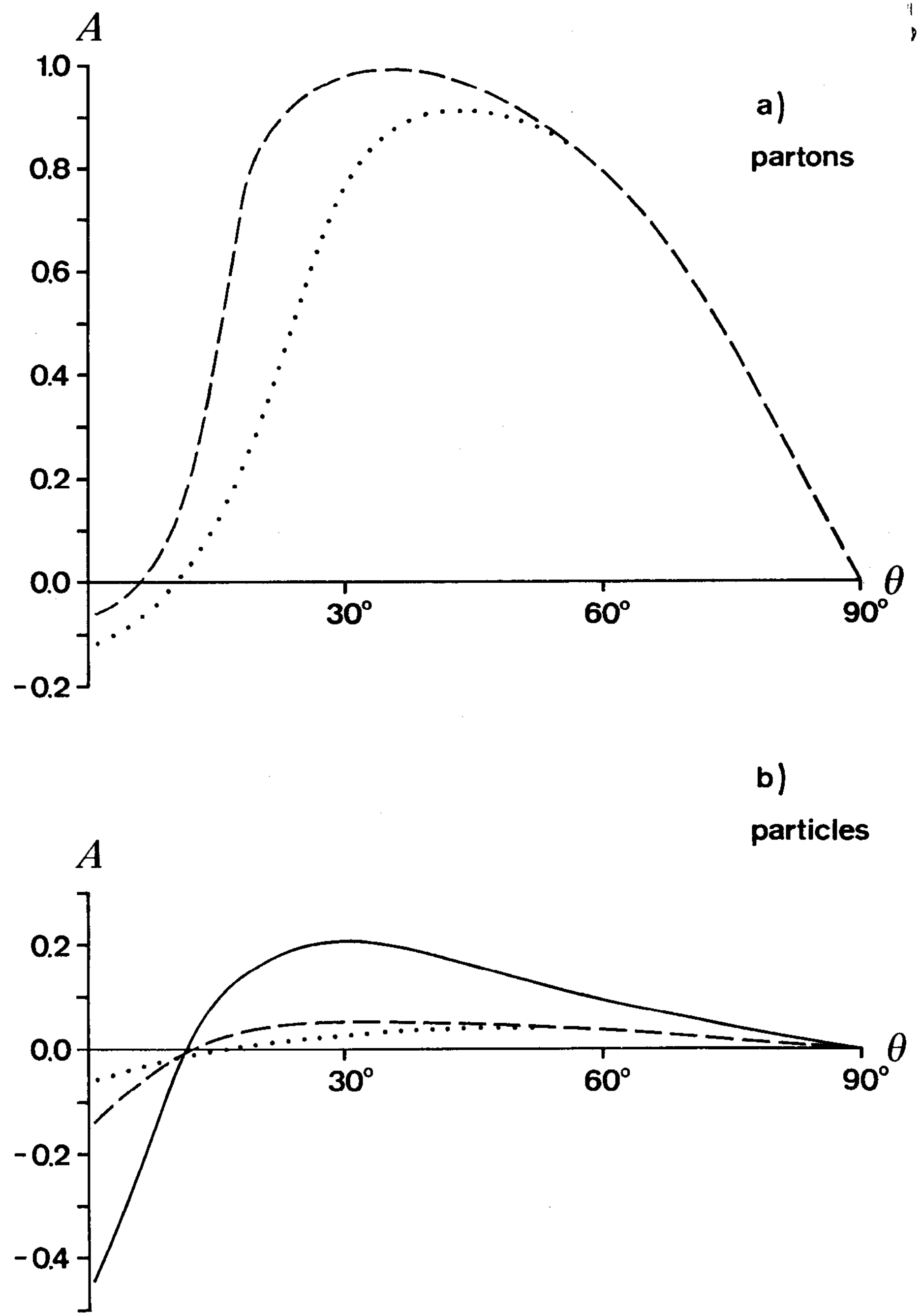
0
1
cos θ

Fig. 5



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a)
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Fig. 6

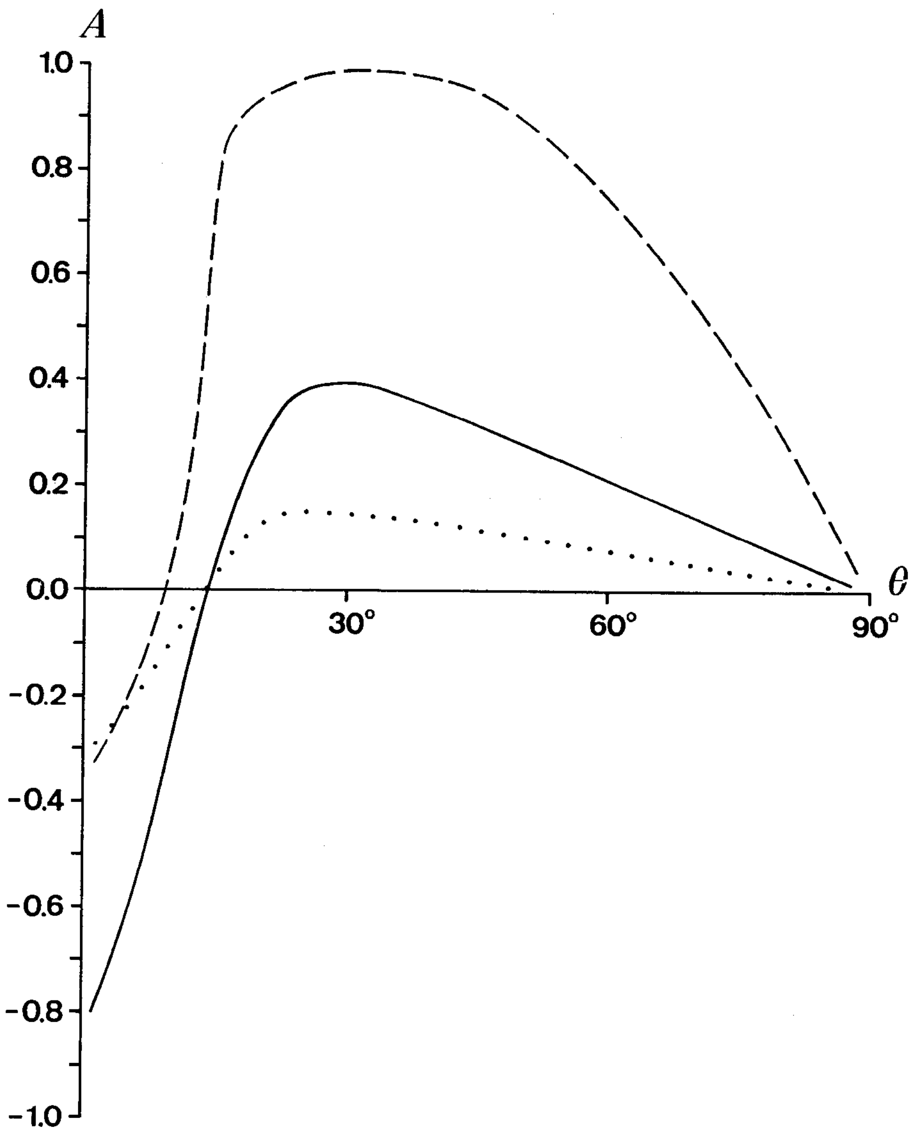
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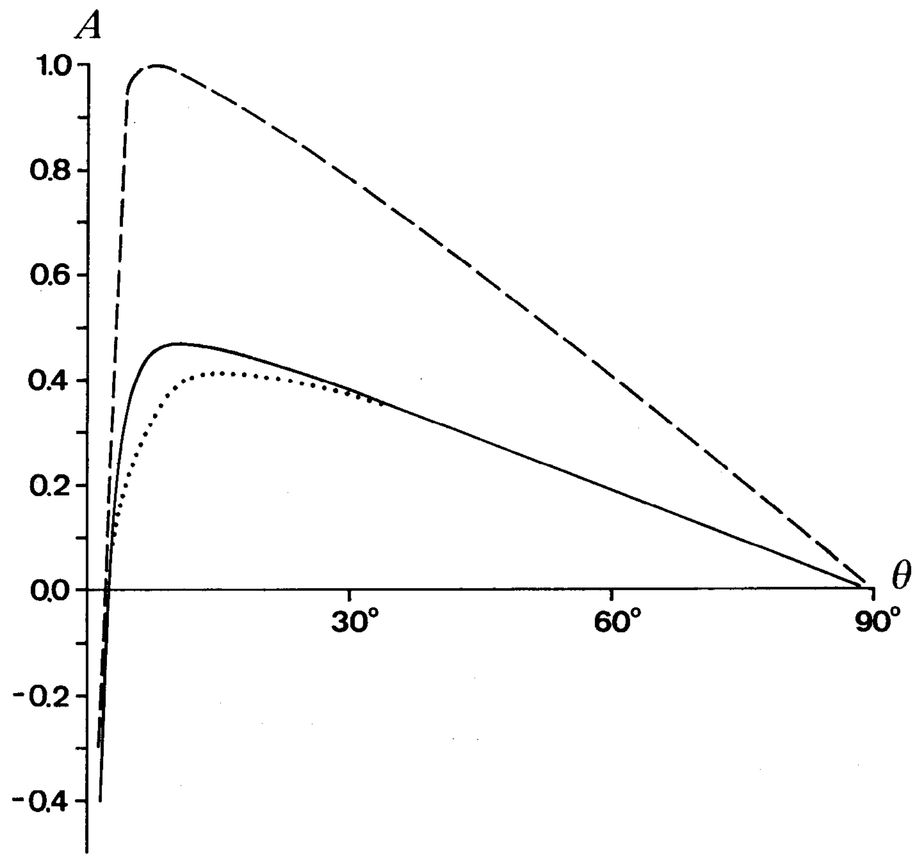
Fig. 7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0.0
-0.2
-0.4
30°
60°
90°
θ

Fig. 8