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Baryon Production in a Topological Model

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Abstract

We develop and make predictions using a topological model for baryon production that we proposed in a previous paper. "Cool" partons close to mass shell are argued to be in one-to-one correspondence with independent domains which break chiral symmetry spontaneously by nonperturbatively developing randomly-oriented chiral condensates. Baryons are formed where there are topological mismatches between the chiral orientations in adjacent domains. We give an algorithm based on the random lattice approach to field theory for calculating the spatial locations of different domains and defining when they are adjacent. We show that the mean baryon multiplicity should grow faster than the number of "cool" partons, which explains the observed increase of baryon production in Υ decays, predicts a rapid increase in baryon production at LEP, implies that baryons should not have a Poisson multiplicity distribution, and means that events with baryons should have a higher mean sphericity. A further Ansatz yields a baryon energy distribution that agrees very well with TPC data.

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1 Introduction

There are two competing phenomenological models of baryons. One is based on the naive non-relativistic Quark Model (NQM) [1], according to which $m_B \approx 3 \cdot m_q$ with $m_q \approx 300 \text{ MeV}$, and in which baryon masses splittings and static properties can be calculated perturbatively by analogy with atomic physics. The other approach is intrinsically non-perturbative, being based on chiral symmetry, according to which $m_q \ll \Lambda_{QCD}$, and the $1/N_c$ expansion [2]. The NQM has been very successful in hadron spectroscopy and elsewhere, and has been used in most jet fragmentation models, but is not justified by QCD for light quarks. On the other hand, although chiral symmetry has been very successful in describing pseudoscalar meson dynamics, the successes of its applications to baryons have been more modest. Chiral symmetry and the $1/N_c$ expansion justify the Skyrme model [3] which reproduces some ratios of static baryonic properties [2] and has been surprisingly successful with meson-baryon scattering phase-shifts [4]. More recently the Skyrme model has scored a notable success by explaining naturally [5] the recent EMC measurements of the spin structure of the proton [6], although it is not impossible to accommodate this result within the NQM [7].

This recent success of the Skyrme model, together with certain difficulties encountered in the description of baryon production in the NQM type of model [8,9], led us to propose [10] a new conceptual model for baryon production in high-energy collisions. In the NQM approach this has usually been described by postulating the production of diquark-antidiquark pairs [11]. Instead we proposed that baryons are produced as a topological mismatches of a "freezing" chiral field. We adopted the standard picture of the initial perturbative QCD jet development, according to which the initial "hot" partons radiate gluons and $q\bar{q}$ pairs populating the final state with "cool" partons close to mass-shell [12]. When these partons convert non-perturbatively into hadrons they each choose independently an arbitrary direction in which to break chiral symmetry spontaneously. A baryon is then produced whenever the chiral directions in adjacent domains mismatch creating a topological defect, much like the monopole or string formation in the early Universe [13]. We showed [10] how the number of baryons could be calculated from the number of adjacent "cool" parton clusters, and illustrated our arguments by simple lattice

calculations. We also speculated how different spatial arrangements of partons could yield different baryon multiplicities.

In this paper we develop our previous ideas by proposing a specific algorithm for characterising "adjacent" cool partons and hence determining the mean multiplicities, multiplicity distributions and to some extent the phase space distributions of baryons in high-energy events. Our algorithm is based on the random lattice approach to field theory [14]. We show that the mean baryon multiplicity should increase faster than the multiplicity of cool partons, which explains qualitatively the greater baryon multiplicity seen [15,16,17] on the Υ -resonance and implies a sharp increase in the baryon multiplicity between PETRA/PEP and SLC/LEP energies. The baryon multiplicity distribution should show, at least at LEP energies, characteristic deviations from the multiplicity distributions of more conventional models. We also argue that events containing more baryons are likely to have larger mean sphericity, and make an estimate of the baryon energy distribution that agrees very well with data.

2 Description of the Model

Inspired by the successful Skyrme model interpretation [5] of the EMC results [6], in ref. [10] we proposed a conceptual topological model for baryon production in jets. Particle production in our model starts with a conventional perturbative QCD shower cascade [12] which is chirally symmetric. This cascade develops until the virtualities of the partons reach some value Q_0 around which non-perturbative phenomena start to take place. The nonperturbative effects in QCD, besides confining quarks, generate quark-antiquark condensates in the vacuum: $\langle 0 | \bar{q}q | 0 \rangle \neq 0$ for $q = u, d, s$. These condensates break spontaneously the $SU(3) \times SU(3)$ chiral symmetry that would otherwise be exact for massless quarks, resulting in the appearance of pseudo-Goldstone bosons, the π , K and octet η [18]. The orientation of the condensates in the internal $SU(3) \times SU(3)$ space may be different in different regions of ordinary 3-space and in our model we assumed that they are selected at random in different regions of space. Therefore there is a possibility of a mismatch resulting in a topological defect expressed mathematically by the fact that $\Pi_3(SU(3)) = \mathbb{Z} \neq 0$. At least in the limit of a large number of colours $N_c \rightarrow \infty$, these topological defects can be interpreted as baryons described by the Skyrme

model [3].

We assumed that the number of domains of equal orientations of vacuum expectation values is equal to the number of "cool" partons. By an extension of Kibble's mechanism [13] for string and monopole formation in the early Universe, we constructed from these domains 3-simplices and have shown that each simplex may give rise to a baryon-antibaryon pair with a probability of $1/16$. The number of 3-simplices was computed by placing the domains on a regular, rectilinear lattice. However in the real world of QCD perturbation theory "cool" partons are stochastically, not regularly, distributed and ways must be found to locate them and to define a measure of their "adjacency" before seeing if their chiral orientations mismatch. In the following we will, therefore, describe how a space position can be defined for every "cool" parton (or for every domain) and how a set of nonoverlapping 3-simplices can be constructed which connects all domains.

The momenta of "cool" partons can be obtained event by event from the Webber-Marchesini algorithm [12]. As "cool" partons we consider partons with virtual masses reduced through the cascade process below some Q_0 value. In old-fashioned perturbation theory, in which energy is not conserved in every virtual emission, a parton emission time is connected to the energy difference between the initial and final states, as defined in Fig. 1, by

$$t = \frac{1}{E_f - E_i} \quad (1)$$

where E_i denotes the initial energy, $E_i = p_z$, and E_f denotes the final energy which is given by

$$E_f = \sqrt{k_z^2 + k_\perp^2} + \sqrt{(p - k)^2 + k_\perp^2} \quad (2)$$

where k and p denote the momenta of the leading and the emitted parton respectively. Assuming that $k_\perp \ll k_z \ll p_z$ we obtain

$$t \approx \frac{2 \cdot k_z}{k_\perp^2} \quad (3)$$

From the knowledge of a parton emission time we can estimate its space coordinates x_n , $n = 1, 2, 3$ to be

$$x_n = v_n \cdot t \quad (4)$$

where $v_n \equiv k_n/E_k$. We interpret these coordinates as characteristic space positions of the domains of parallel vacuum expectation values of the "frozen" chiral field and there are, by construction, as many space sites as "cool" partons in a shower.

Our next task is to build out of them a random lattice, i.e. to construct non-overlapping simplices whose vertices are these random sites. We used for this purpose an elegant algorithm developed in ref [14] for the investigation of a random lattice field theory. Consider an arbitrary set of 4 random lattice sites. These sites lie on a surface of a sphere in 3 dimensions which we will call in the following the circumscribed sphere. If the inside of this sphere is free of all lattice sites, then this set of 4 sites makes a simplex with vertices given by the sites. The simplices constructed in this way define our random lattice, which has the following key properties: there is no overlap between the volumes of any two simplices and every site belongs to at least one simplex.

According to our generalized Kibble prescription [10] every simplex has a fixed probability to turn into a baryon-antibaryon pair. We have shown that for flavour $SU(2)$ this probability is $1/16$, and computations [19] of topological susceptibilities of gauge fields on a lattice suggest that it is probably similar for $SU(3)$. For the purpose of this paper we will neglect the possible difference between $SU(2)$ and $SU(3)$ and compute the baryon numbers using a probability of $1/16$ for all kinds of baryons.

We have found out in Monte Carlo (MC) computations that the above random lattice algorithm subdivides a given number of sites into a relatively fixed number of simplices, with little apparent variation due to possible different space distributions of the sites. For example, for a 10-site e^+e^- event at $\sqrt{s} = 30 \text{ GeV}$ our MC produces on the average 20.7 simplices with a rms spread of 2.1 simplices from event to event. If these 10 sites have a spatial distribution characteristic of the Υ -resonance our algorithm produces 21.2 simplices with a similar spread. Similarly, a 20-site event from a $\sqrt{s} = 92 \text{ GeV}$ e^+e^- reaction leads to 67.5 simplices with a spread of 4.4 simplices, whereas a 20-site event at $\sqrt{s} = 180 \text{ GeV}$ gives 66.6 simplices with the same spread. We have investigated in a similar way events with numbers of sites between 5 and 50 and found out that the number of simplices was very tightly correlated to the number of partons but not to their spatial distribution.

The random lattice algorithm shows further that the simplex multiplicity per parton is varying with the number of partons. For events with 4 partons we produce only one simplex, for 5 partons 3 simplices, for 10 partons around 20 simplices, and for 20 partons around 65 simplices. The simplex multiplicity per parton grows then with the number of partons from $1/4$ to $3/5$ to 2 and to 3.25 respectively. In Fig. 2 we show the ratio of simplex multiplicity per parton as a function of parton number for the range of parton numbers which are relevant in studies of e^+e^- interactions up to 200 GeV centre-of-mass energies. We see that this ratio rises sharply for low numbers of partons and that this rise starts to level off only above a multiplicity of around 20 partons. The maximum ratio which is relevant for e^+e^- interactions lies around 4.5. For an infinite number of randomly distributed partons this ratio would be equal to $\frac{96}{435}\pi^2 = 6.8$ [14]. In our model the simplex multiplicity is, as we discuss below, directly related to the baryon multiplicity, so the probability per parton to produce a baryon also grows with the number of partons. This is a characteristic property of the model distinguishing it from the NQM type of models, in which the diquark production probability is the same for every gluon or quark, irrespective of the number of other quarks or gluons in the event [11]. In Section 3 we will therefore discuss how this property could translate itself into the effects which are more observable than the number of partons.

Finally we should explore in more details the possible relation between simplices and baryon pairs. In reference [10] we assumed that every simplex can turn into a baryon-antibaryon pair with the same probability, which in $SU(2)$ is $1/16$. We have worked out the spatial coordinates of the simplex vertices, and found out that the average radius of a circumscribed sphere is, in e^+e^- events, around 10 fermi which is considerably more than a proton radius. However, the parton emission times (3) and therefore also vertex positions (4) are computed perturbatively, without taking into account confinement effects. In particular, the parton transverse momentum $k_{\perp}$ can become very small, which leads in turn to space distances which are larger than the confinement scale. A remedy for this problem is to introduce in (3) a small cut-off mass, i.e. to replace $1/k_{\perp}^2$ with $1/(k_{\perp}^2 + m_1^2)$. After a confinement mass $m_1^2 = 0.2 GeV^2$ was introduced, the size of the average circumscribed sphere diminished to around 6 fermi but remained still considerably larger than a proton radius. These consid-

erations suggest that as an alternative strategy, instead of considering every simplex on an equal footing, we could select only ones with sizes smaller or comparable to the proton radius. Therefore, in this paper we will follow two approaches: one in which we allow every simplex to be turned into a baryon-antibaryon pair with the probability of $1/16$, and one in which we allow only simplices with sizes smaller or equal to the proton size to transform into protons.

Summarizing, we have in our model for baryon production in jets the following main steps:

- Production of "cool" partons. We used for this purpose the standard Webber-Marchesini algorithm [12] in its Lund version [11].
- For every "cool" parton we compute from equations (3) and (4) the space positions. We consider a set of space positions obtained in this way as sites of a lattice.
- With the help of the random lattice method [14], we combine the lattice sites into simplices.
- The simplices are transformed into baryon pairs with a fixed probability, which may be zero for large simplices.

3 Baryon Multiplicities and Momenta

We would like first to test our model by comparing its predictions to the e^+e^- data on baryon production. In ref. [10] we noted that our model with a conventional choice of the QCD parameters Λ and Q_0 reproduces the observed baryon multiplicity at $\sqrt{s} = 30 GeV$. At this energy the multiplicity of protons or antiprotons was observed to be around 0.6 ± 0.1 [20,21]. This multiplicity can be reproduced in the two variants of our model with different sets of Λ and Q_0 values:

1. If we allow every simplex irrespective of its size to become a baryon-antibaryon pair: $\Lambda = 0.2$ and $Q_0 = 0.72 GeV$.
2. If we accept only simplices with sizes smaller or equal to the proton radius: $\Lambda = 0.2$ and $Q_0 = 0.4 GeV$.

These two choices of Λ and Q_0 define two variants of our topological model.

The characteristic property of the topological model is the variation of baryon production probability per parton with the number of

Λ, Q_0 [GeV] Υ^{em}	Topological Model		Topological Model		Conventional Model		Data
	0.2, 0.72	0.53	0.2, 0.4	0.73	0.2, 0.4	0.74	
$\sqrt{s} = 9.4$							0.51 ± 0.03 [17]
Υ^{em}							0.64 ± 0.17 [15]
							0.60 ± 0.1 [16]
$\sqrt{s} = 10$							0.27 ± 0.02 [17]
Υ^{off}							0.10 ± 0.04 [15]
							0.40 ± 0.06 [16]
$\sqrt{s} \approx 30$							0.53 ± 0.07 [20]
							0.67 ± 0.06 [21]
$\sqrt{s} = 92$							
$\sqrt{s} = 180$							

Table 1: Comparison of baryon or antibaryon multiplicities of topological and conventional-type models with data. The models were tuned to agree with data at $\sqrt{s} = 30$ GeV.

partons, as shown in Fig. 2. In the following we will discuss the consequences of this behaviour for the energy dependence of the average baryon multiplicities, baryon multiplicity distributions and sphericities in events containing baryons. To quantify the differences between the topological model and ones based on the diquark idea [11] we also constructed a simple-minded conventional model in which baryons are produced from diquarks coupled directly to gluons. The gluon-diquark coupling was determined to reproduce the baryon multiplicity at $\sqrt{s} = 30$ GeV.

3.1 Average Baryon Multiplicities

A clear test of the model can be provided by a comparison of its predictions with the average baryon multiplicities measured at different energies. In Table 1 we show the predictions of our model and compare it with data at various energies. From Fig. 2, we would expect that baryon multiplicities in the topological model grow quicker with energy than in the conventional model.

Table 1 shows a satisfactory agreement between data and predictions of both the topological and conventional model. Unfortunately, at $\sqrt{s} = 10$ GeV, where the topological and conventional model predictions differ significantly, the data from different experiments show discrepancies which are larger than the differences between models. On the other hand, in the Υ region the comparison of the model with data is obscured by possible phase-space effects. To see this, we note that the multiplicity on the Υ , which is 0.73 in both the conventional and topological models, is built from the following contributions: 0.31 comes from events with one baryon-antibaryon pair, 0.24 with two baryon-antibaryon pairs, and 0.18 from events with 3 or more baryon-antibaryon pairs. Obviously, it is difficult to imagine how 3 baryon-antibaryon pairs can be produced with 9.4 GeV of total energy, without being squeezed by phase-space constraints. From Lund model studies, it is known that baryon production is slightly diminished by phase-space effects already in the off- Υ region [8].

We expect that at center-of-mass energies around 30 GeV the phase-space effects will become negligible, because the baryon multiplicity is similar to that on the Υ resonance, but there is a factor of 3 more energy to be distributed. In general, as the energy increases the phase-space effects should play a smaller role because, even in the topological model, the baryon multiplicity grows slower than the energy. Therefore we believe that the most significant test of our model will be the comparison of its predictions with data from the Z^0 -region in e^+e^- annihilation, which should soon be possible. The topological model shows in this region a sizeably larger increase in baryon production than the conventional model. Of course, this difference would become even more pronounced if the baryon content of jets with considerably higher energies could be measured, as at LEP 2 with $\sqrt{s} = 180$ GeV. We would also expect similar effects to be observed at the Fermilab collider.

3.2 Baryon Multiplicity Distributions

The cluster-number-dependent baryon formation probability characteristic of the topological model leads to correlated proton-proton or antiproton-antiproton emissions. To see this effect, we have plotted in Figs. 3a and 3b the antiproton multiplicity distributions (at $\sqrt{s} = 30$ GeV) for the two variants of our model, and compared

them to normalized Poisson distributions. The deviations from the Poisson distribution are a reflection of the nonuniform baryon formation probability. The QCD shower cascade leads to uncorrelated parton emission, therefore in our conventional model we would expect a Poisson-like baryon multiplicity distribution. The deviation from the Poisson distribution is large enough to be easily observable for one of the variants of our model at $\sqrt{s} = 30 \text{ GeV}$ and for both variants at the Z^0 , as seen in Figs. 4a and b.

The meson multiplicity distributions in e^+e^- annihilation at low energies show clear deviations from the Poisson shape [22]. The correlations which lead to these deviations can be explained by differences in the average multiplicity of different quark fragmentation processes. In particular, it was found that at 30 GeV these correlations were due to higher multiplicity of b-quark fragmentation [23]. In our case also, the parton emission probability may be quark-flavour-dependent due to quark mass effects. This dependence disappears, however, with growing energy. We checked that this effect, when translated to baryon production in our conventional model, becomes small already at $\sqrt{s} = 30 \text{ GeV}$.

3.3 Baryonic Sphericities

The average particle multiplicity in e^+e^- annihilation reactions is sphericity-dependent [22]. This can be understood, in the conventional model, through the increase of parton multiplicity with sphericity. In the topological model, the baryon multiplicity grows even faster than the parton multiplicity. We would therefore expect that the baryon multiplicity should also depend on sphericity, and that its increase should be stronger than for other particles.

To quantify this effect, we have computed in the topological model the parton sphericity distribution and compared it with the sphericity distributions when baryons were produced. We show them in Figs. 5a,b for events with $\sqrt{s} = 30 \text{ GeV}$ and in Figs. 6a,b for events in the Z^0 region. In Table 2 we show the average sphericities for events without baryon selection, and with one, two or three baryons produced.

In comparing these results with real data care must be taken since we computed only *parton* sphericity distributions, which are somewhat different from the real ones. Nevertheless, we believe that the differences between baryonic and non-baryonic distributions computed

$\Lambda, Q_0 [\text{GeV}]$	Topological Model	Topological Model	Conventional Model
$\sqrt{s} = 30 \text{ GeV}$	0.2, 0.72	0.2, 0.4	0.2, 0.4
$\langle S \rangle$	0.09	0.09	0.09
$\langle S \rangle_{1 \text{ baryon}}$	0.12	0.16	0.10
$\langle S \rangle_{2 \text{ baryon}}$	0.16	0.22	0.12
$\sqrt{s} = 92 \text{ GeV}$			
$\langle S \rangle$	0.07	0.07	0.07
$\langle S \rangle_{1 \text{ baryon}}$	0.09	0.11	0.08
$\langle S \rangle_{2 \text{ baryon}}$	0.12	0.16	0.10
$\langle S \rangle_{3 \text{ baryon}}$	0.14	0.20	0.12

Table 2: Comparison of average sphericities for events with different number of baryons.

in our models indicate the size of the effect to be expected in the real data. We suggest rejecting b-quark events from the data when comparing the baryonic and nonbaryonic sphericities.

3.4 Baryon momentum distribution

The Kibble method [13] allows one to count the number of topological defects arising from random chiral field orientations. This number is then related, in a straightforward fashion, to the number of baryons per event. On the other hand, the relation to the baryon momentum distribution is theoretically less clear. However, our construction of baryons from four simplex vertices suggests that we could relate baryon momenta to the momenta of partons forming a simplex. We have found that the best results are obtained assuming that a baryon acquires the momentum of one of the simplex partons. We compare the baryon momentum distributions obtained in this way with data in Figs. 7a and b for the two variants of our model. The $\Lambda = 0.2, Q_0 = 0.4 \text{ GeV}$, proton-size-restricted variant of our model leads to a very good agreement with data, as seen in Fig. 7b. The small differences between data and the model observed at low energies can be attributed to confinement effects, as discussed above. In this

plot we have not made any attempt to correct for them. The momentum distribution obtained in the another variant of our model, see Fig 7a, is, however, inconsistent with data.

4 Conclusions

We have shown in this paper that the topological approach to baryon production in high-energy collisions that we proposed previously [10], implemented with the random lattice algorithm [14] for locating independent domains, successfully reproduces qualitatively the different baryon multiplicities seen on the Υ resonance [15,16,17] and in the e^+e^- continuum at $\sqrt{s} = 30$ GeV [21,20]. The model predicts an increase in the baryon multiplicity at higher (SLC and LEP) e^+e^- centre-of-mass energies which is faster than the increase in the parton multiplicity computed in perturbative QCD. This prediction distinguishes our model from conventional fragmentation models [11,12] that predict a constant baryon-to-parton ratio in the PEP/PETRA to SLC/LEP energy range. Another testable prediction of our model is that the baryon multiplicity distribution should not be Poisson. We also find that e^+e^- events containing baryons should have larger sphericity than events without baryons.

Several more steps are needed to develop our topological approach into a fully-fledged Monte-Carlo programme for jet fragmentation into baryons. For example, we do not yet have a reliable procedure for calculating the momenta and energies of the produced baryons. We have shown that identifying the baryon momentum with that of one of the partons participating in the 3-simplex that creates it reproduces the baryon energy spectrum measured by the TPC Collaboration [20]. This procedure could in principle be extended to estimate the baryon-antibaryon and baryon-baryon correlations in momentum space, but we are not yet able to confront our model with the recent ARGUS data [24], which appear to exclude simple-minded diquark-antidiquark pair production without an intervening meson in the Lund model. However, we expect that baryon-antibaryon momentum and flavour correlations in our model will be weaker than in the simple-minded diquark-antidiquark pair-production model.

We are also not yet able to discuss the apparent suppression of Δ production relative to n, p production, and the relative abundances of strange baryons [8,9]. In our topological approach, Δ production

should be suppressed because it requires higher angular momentum in the chiral cloud making up the baryon.

So far we have only calculated the "cool" parton distribution, and hence baryon production, in e^+e^- collisions. Our approach could be extended to other high-energy jet processes, for example in $p\bar{p}$ collisions at CERN and Fermilab, where we expect qualitatively similar effects.

It has not escaped our attention that our topological approach to baryon production could also be applied to high-temperature processes, such as the quark-hadron phase transition in the early Universe or in relativistic heavy ion collisions [25]. However, in these cases final-state interactions leading to baryon-antibaryon annihilation should be considered. We plan to return to these processes in a future publication.

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Figure Captions

Fig. 1. Example of a perturbative process whereby a virtual "hot" parton splits into two less virtual "cooler" partons.

Fig. 2. Growth of the ratio between simplex number and "cool" parton number in the e^+e^- continuum.

Fig. 3. The baryon multiplicity distributions in e^+e^- annihilation at $\sqrt{s} = 30$ GeV in variants of our topological model (a) without and (b) with a cutoff on the radii of the spheres circumscribing simplices of "adjacent" partons.

Fig. 4. As for Fig. 3, but at the Z^0 peak, $\sqrt{s} = 92$ GeV.

Fig. 5. The parton sphericity distributions at $\sqrt{s} = 30$ GeV for events containing different numbers of baryons, in the model variants (a), (b) described in the caption of Fig. 3.

Fig. 6. As for Fig. 5, but at the Z^0 peak, $\sqrt{s} = 92$ GeV.

Fig. 7. Baryon energy distributions at $\sqrt{s} = 30$ GeV estimated by identifying the baryon momentum with that of one of the "cool"

partons in the cluster creating it, in the model variants (a) and (b) described in the caption of Fig. 3.

References

- [1] For a review see: J.J.J. Kokkedee, *The Quark Model*, W.A. Benjamin, New York, 1969
- [2] E. Witten, Nucl. Phys. B223 (1983) 422, *ibid* 433
G. Adkins, C. Nappi and E. Witten, Nucl. Phys. B228 (1983) 433
for the 3 flavor extension of the model see: E. Guadagnini, Nucl. Phys. 236 (1984) 35 and P. O. Mazur, M. A. Nowak and M. Praszalowicz, Phys. Lett. 147B (1984) 137
- [3] T.H.R. Skyrme, Nucl. Phys. 31, (1962) 556
- [4] M.P. Mattis, M. Karliner, Phys. Rev. D31 (1985) 2833
M. Karliner, M.P. Mattis, Phys. Rev. Lett. 56 (1986) 428
M. Karliner, M.P. Mattis, Phys. Rev. D34 (1986) 1991
- [5] S. Brodsky, J. Ellis, M. Karliner, Phys. Lett. 206B (1988) 309
J. Ellis, M. Karliner, Phys. Lett. 213B (1988) 73
- [6] EMC Collaboration, J. Ashman et al., Phys. Lett. 206B (1988) 364
- [7] A.V. Efremov and O.V. Teryaev, JINR Report E2-88-287 (1988)
G. Altarelli and G.G. Ross, B212 (1988) 391
R. D. Carlitz, J.C. Collins and A. Mueller, Phys. Lett. B214 (1988) 229
- [8] W. Hofmann, Proc. Int. Symp. on Lepton and Photon Interactions at High Energies, Hamburg, 671 (1987) and
Ann. Rev. Nucl. Part. Science 38 (1988) 279
- [9] D. H. Saxon, RAL 88-102, to be published in Proc. Workshop on
Diquarks, Turin 1988
- [10] J. Ellis and H. Kowalski, Phys. Lett. 214B (1988) 161
- [11] B. Andersson, G. Gustafson, G. Ingelman, T. Sjöstrand, Phys. Rep. 97 (1983) 31
T. Sjöstrand, Int. J. Mod. Phys. A3 (1988) 751

- [12] G. Marchesini, B.R. Webber, Nucl. Phys. B238 (1984) 1
- [13] T.W.B. Kibble, J. Phys. A: Math. Gen., Vol. 9. (1976) 1387
- [14] N. H. Christ, R. Friedberg and T. D. Lee - Nucl. Phys. B202 (1982) 89
- [15] H. Albrecht et al. (DASP II), Phys. Lett. 102B (1981) 291
- [16] S. Behrends et al. (CLEO), Phys. Rev. D31, (1985) 2161
- [17] H. Albrecht et al. (ARGUS), Z. Phys. C39 (1988) 177
H. Albrecht et al. (ARGUS), DESY 89-014
- [18] J. Gasser, H. Leutwyler, Phys. Rep. 87 (1982) 77
- [19] A.S. Kronfeld, Nucl. Phys. B (Proc. Suppl.) 4 (1988) 329
- [20] H. Aihara et al. (TPC), LBL-23737 (1988)
- [21] W. Braunschweig et al. DESY 88-164 (1988)
- [22] M. Althoff et al. (TASSO), Z. Phys. C22 (1984) 307
M. Dittmar, Interner Bericht, DESY F1-85-01
- [23] M. G. Bowler and P. N. Burrows, Z. Phys. (1986) C31
- [24] H. Albrecht et al. (ARGUS), DESY 89-013
- [25] T. A. DeGrand, Phys. Rev. D30 (1984) 2001

Fig. 1

Simplex formation

Fig. 2

Antiproton Multiplicities at $E_{CM} = 30$ GeV

Fig. 3a

Antiproton Multiplicities at $E_{CM} = 30$ GeV

Fig. 3b

Antiproton Multiplicities at Z^0

Fig. 4a

Antiproton Multiplicities at Z^0

Fig. 4b

Parton Sphericity at $E_{CM} = 30$ GeV

Fig. 5a

Parton Sphericity at $E_{CM} = 30$ GeV

Fig. 5b

Fig. 6a

Fig. 6b

$z \cdot dN/dz$ Distribution

Fig. 7a

$z \cdot dN/dz$ Distribution

Fig. 7b