CERN-TH.4345/85

HUMP-BACKED QCD PLATEAU IN HADRON SPECTRA

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A B S T R A C T

New data on inclusive energy distributions of hadrons from quark jets in e^+e^- annihilation are shown to agree with the quantitative predictions of perturbative QCD, supporting the hypothesis of local parton-hadron duality.

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1. INTRODUCTION

In previous papers¹⁾⁻³⁾ we have discussed in detail the idea of local parton-hadron duality (LPHD) - the perturbative approach to the description of the hadronic structure of QCD jets. To reduce the ignorance about confinement dynamics, one should compare the perturbatively calculable characteristics of quark-gluon (parton) systems, namely, their parton multiplicities, inclusive energy and angular spectra, correlations, etc., with corresponding characteristics of multihadron states, produced in hard processes.

We continue here the discussion of energy spectra started in Ref. 1). Recent e^+e^- annihilation data seem to support strongly the LPHD hypothesis that predicts the structure of the hadron spectrum to be similar to the hump-backed parton plateau, following from the QCD coherence in the soft gluon bremsstrahlung.

The similarity between a hadron system and its parton skeleton in angular distributions of particles was demonstrated in Ref. 4), where the so-called "string effect", i.e., the phenomenon of the particle drag by a gluon jet in $q\bar{q}g$ events, has been explained in the LPHD framework in terms of coherent QCD radiation from the three-element colour "antenna".

2. HUMP-BACKED PLATEAU IN INCLUSIVE SPECTRA AND PRESENT EXPERIMENTS

The deduction of modified leading log approximation (MLLA) predictions for the energy spectrum of soft partons in jets has been discussed earlier in detail in Ref. 2). The height of the parton plateau $D = (x/\sigma) \cdot d\sigma/dx$ ($x \approx P/E_j \approx E/E_j \ll 1$, $x > x_{\min} = Q_0/E_j$) increases non-uniformly with the jet energy E_j due to QCD cascade production of high $k_{\perp}$ particles. The coherence of gluon radiation damps the multiplication of "slow" particles ($x \sim x_{\min}$), the region $\ln x/x_{\min} \approx 0.35 \ln 1/x_{\min}$ being populated most intensively. As a result, a "hump" appears and grows in the inclusive spectrum. At asymptotically high E_j the shape of the spectrum versus $\ln x/\ln x_{\min}$ becomes independent of the parameter Q_0 that cuts off parton cascades. With decreasing Q_0 , the parton multiplicity grows rapidly due to more intensive branching at the last steps of the cascade where $k_{\perp}^2 \approx Q_0^2$ and $\alpha_s(k_{\perp}^2)$ is the largest. However, the spectrum increases similarly for fixed $\ln x/\ln x_{\min}$ so that its shape turns out to be independent of Q_0 (in asymptotics $\ln E_j/\Lambda \gg \ln Q_0/\Lambda$) being in this sense infra-red stable. This observation, i.e., insensitivity of the spectrum shape to the evolution stage where the perturbation

theory (PT) breaks down, has allowed the suggestion that hadron spectra should be similar to the parton one with $Q_0 \approx \Lambda$ ("limiting parton spectrum").

The first comparison with TASSO results on the x-distribution of $\pi^\pm$ ⁵⁾ has already shown that the suggestion was quite reasonable ¹⁾. Though data were meagre (only 1-2 experimental points indicated the hump) the agreement looked very impressive. The PT prediction for the shape of spectra contains no parameters (except $\Lambda \approx 150$ MeV), and single log (SL) effects have shifted the position of maximum [in comparison with double log (DL) predictions $\ln x/x_{\min} = \frac{1}{2} \ln 1/x_{\min}$] exactly to the right place.

More detailed measurements of hadron spectra at PEP have appeared in the last year, in particular, the spectrum of $\pi^\pm$ ⁶⁾ (see Fig.1). New data of the TPC-collaboration not only confirm the presence of a hump but also maintain the nice tradition of coinciding with the MLLA curve. Its over-all normalization (phenomenological coefficient of similarity between parton and hadron spectra) $K_g^{\pi^\pm} = 1$, has been fixed by the TASSO data. Now the hump-backed plateau is manifested most clearly in HRS collaboration data ⁷⁾ on all charged hadrons (Fig.2).

So, the existence of the hump-backed plateau is proved experimentally. Moreover, it is practically established now that the observed structure of spectra is dominated by the physics of QCD coherence, not being an artefact of one or another non-asymptotic effects (phase-space, charmed hadron decays, and so on).

Surely, the main lesson of these observations is not the proof of coherence: it would be inexcusable to use hard hadron processes for checking quantum mechanics. Of real importance is the fact that the PT-coherence has revealed itself in hadron spectra, i.e., confinement has not disturbed the PT picture of particle generation. In principle, one could imagine a non-local scheme of hadronization (being self-consistent though very unnatural from the viewpoint of the space-time picture) where each parton generates its own hadron plateau, so that the PT hump will never be seen in hadron spectra even in asymptotics (see below). The fact that non-perturbative effects do not radically rearrange a parton system at the confinement stage provides evidence in favour of locality of parton branching and hadronization processes in configuration space ^{8),9)}, thus supporting the hypothesis of LPHD.

At first sight, such a close correspondence of parton and $\pi^\pm$ spectra, as

in Fig. 1, might seem rather strange, since a considerable part of π 's is known to come from resonance decays. If this correspondence does not disappear as an accidental coincidence, in particular, after accounting for non-asymptotic corrections to the MLLA prediction, an important physical phenomenon would be established: resonance physics is naturally embedded into the picture of PT cascades, i.e., an aggregate contribution of resonances is dual to the parton description of the last steps of evolution.

To realize such a duality, one must accommodate a parton shower to the inclusive generation of the particular hadron h . It looks natural to connect the end-point of the cascade with the hadron mass M_h by the choice $Q_0 \approx M_h$, thus giving a physical meaning to the formal PT cut-off parameter Q_0 . The parton momentum distribution becomes harder with increasing Q_0 and the hump in the spectrum $D^h(x)$ shifts to the right from its position in the limiting parton distribution $D_0(x)$ with $Q_0 = \Lambda$. On the contrary, spectra of decay products of massive resonances become softer, so the distribution of secondary pions could in principle coincide with the limiting one. It would be interesting to check this scenario quantitatively.

Figure 1 confirms that hadron momenta at the maximum of the spectrum D^h increase with the hadron mass. For the PT picture, such a behaviour is quite natural: only particles with $p > p_{\perp} > M$ are effectively multiplied, so the whole cascade stiffens. This shift is illustrated by curves in Fig. 1 obtained by the simple scale recalculation from the limiting parton spectrum D_0 :

$$D^h(\zeta, W) = K^h \cdot D_0(\zeta, W). \quad (1)$$

On the left-hand side ζ is related to experimental quantities

$$\zeta = y/y_{\max}, \quad y = \ln \frac{E_k + p_k}{M_h},$$

while on the right-hand side the universal function D_0 is calculated with $Q_0 = \Lambda$ as described in Refs. 1) and 2).

We use the same normalization of the curves (coefficients K^k and K^p) as determined from TASSO data in Ref. 1) where the approximate similarity of experimental π , K and p spectra has been observed in terms of the ζ variable. Such recalculation reflects correctly at least the fact that at high W the

position of the maximum in the ζ distribution is nearly independent of the mass. At $\ln M/\Lambda < \ln W/\Lambda < (\ln M/\Lambda)^2$

$$\zeta_{hump} \approx \frac{1}{2} - C_0 \sqrt{\mathcal{L}_s(W)} + C_1 \mathcal{L}_s(W) / \sqrt{\mathcal{L}_s(M)}. \quad (2)$$

At $\ln W/\Lambda > (\ln M/\Lambda)^2$ the spectra reveal an exact similarity (independence ζ_{hump} of M). For a detailed study of the connection between Q_0 and M_h one needs a more accurate theoretical analysis of inclusive characteristics of the truncated cascade and precise measurements of massive hadron spectra.

As we discussed earlier¹⁾, the factor K^h in (1) should strongly depend on the hadron mass. Just this effect appears to be mainly responsible for the smaller yield of protons in comparison with pions. However, K^h may contain some additional dependence on the hadron (h) quantum numbers which is intimately connected with the hadronization mechanism. It would be very interesting to study such a dependence in experiment.

For instance, the ratio $K^\pm/\pi^\pm$ might demonstrate the strangeness suppression. Unexpectedly enough, fitting the TASSO data⁵⁾ showed practically no such suppression, additional to the mass suppression [see Ref. 1)]. A similar conclusion can be deducted from Monte Carlo parton shower model simulations¹⁰⁾ which, without including any additional strangeness suppression, predicted even less $K^\pm$ production than was seen by TASSO.

The new TPC data⁶⁾ disagree with TASSO and change the situation. Figure 1a shows that the energy spectrum of $K^\pm$ is in good accordance with Eq. (1), if one includes a strangeness suppression factor about 0.7 (the dashed curve in Fig.1a).

Note that the strangeness suppression may look differently for mesons and baryons. Experimental data of several groups confirm such a possibility. Figure 1b shows that the shape of the energy distributions of Λ and p agrees with Eq. (1), but the additional Λ/p suppression factor (after removing the mass effects) is about 0.3 in contrast to the meson case.

Further study, both theoretical and experimental, of the role of hadron quantum numbers is very desirable.

3. THE DIP IN RAPIDITY SPECTRA. "PRO" AND "CONTRA"

The reader may have noticed that we have shunned the usage of the popular term "rapidity" in the discussion of the hump-backed plateau where variables $\ln xE/\Lambda$ and $y = \ln (E+p)/M$ have occurred. This shunning is noteworthy so we single out its explanation in a separate section.

The dip in inclusive rapidity spectra $dn/dy_{\parallel}$

$$y_{\parallel} = \frac{1}{2} \ln \frac{E + p_{\parallel}}{E - p_{\parallel}} = \ln \frac{E + p_{\parallel}}{M_{\perp}} \quad (3)$$

at $y_{\parallel} \approx 0$ recently observed in e^+e^- annihilation⁵⁾⁻⁷⁾ is widely discussed as evidence in favour of coherent effects (see Fig.3). As a matter of fact, such a treatment of the rapidity dip proves to be a fallacy.

In the framework of the old theory of strong interactions with limited $p_{\perp}$ the structure of energy ($\ln x^{-1}$) and angular ($\ln \theta^{-1}$) spectra appeared roughly the same, so that one was allowed not to distinguish between $\ln x$, y or $y_{\parallel}$. Following this tradition, one might expect that the hump-backed shape of energy distributions $dn/d \ln x^{-1} \approx dn/dy$ should be repeated in the rapidity spectra $dn/dy_{\parallel} \approx dn/d \ln \theta^{-1}$. However, the QCD branching picture contradicts this expectation, predicting a maximum instead of a dip at $y_{\parallel} \approx 0$. The qualitative dissimilarity of the structure of y - and $y_{\parallel}$ -spectra originates from the fact that it is the high $p_{\perp}$ processes which yield the phenomena connected with the increase of the plateau.

Therefore the old-fashioned parton picture sets a trap for the treatments of the observed rapidity dip. Placing emphasis on the rapidity distribution as a way of searching for coherence looked justifiable, since there were here no phase space effects resulting in a dip, unlike the case of the y -spectrum which vanishes kinematically as $y^2 dy \sim p^2 dp$ at $y \rightarrow 0$. However, it is nothing but the bias, connected with the determination of a jet axis involved in the definition of $y_{\parallel}$, that is responsible for the occurrence of the $y_{\parallel}$ -dip. Meanwhile, the manifestation of coherence, if any, turns out to be rather indirect here. Therefore this way is far from being the best one for testing coherence effects.

Consider in some more detail the difference between distributions over

"total" (y) and "longitudinal" ($y_{\parallel}$) rapidities. The appearance of a $y_{\parallel}$ spectrum rising monotonically at $y_{\parallel} \rightarrow 0$ ("d" shape; "d" = dromedary in Fig.3), as well as the influence of the coherence on particle distributions can be illustrated with the help of first order QCD as the simplest model for parton multiplication.

We start with an old-fashioned plateau of hadrons with limited transverse momenta $k_{\perp} \approx k_{\perp} \sim R^{-1}$ for a quark jet with energy E

$$p(k) \equiv dn/d \ln k, \quad p(\theta) \equiv \frac{dn}{d \ln y_{\parallel}} \approx \frac{dn}{d \ln 1/\theta}, \quad p(k) = p(\theta) = C_2 \quad (4)$$

for $R^{-1} \ll k \ll E$, $(ER)^{-1} \ll \theta_k \ll 1$ (see shaded areas in Fig.4a-c). Accounting for a gluon with energy ε and emission angle θ_0 , let us use a double-log expression for the radiation probability

$$dw \sim \mathcal{L}_s d\varepsilon/\varepsilon \cdot d\theta_0/\theta_0 \cdot \mathcal{J}(\varepsilon\theta_0 - R^{-1}). \quad (5)$$

The step function θ restricts here the transverse momentum $p_{\perp} \approx \varepsilon\theta_0 > R^{-1}$ to ensure the gluon's existence [$t_{\text{radiation}} \sim \varepsilon/p_{\perp}^2 < t_{\text{hadronization}} \sim \varepsilon R^2$] and, at the same time, applicability of the PT approach ($\alpha_s(p_{\perp}^2)/\pi < 1$).

How does the gluon contribute to the hadron yield? The existing diversity in hadronization pictures can be closely related to the PT coherence phenomena. Indeed, from the standpoint of the orthodox parton model, one might expect the gluon to give rise to a sub-jet of hadrons with $k\theta' \sim R^{-1}$ (θ' being the angle between the registered hadron and the gluon) and an energy plateau as wide as

$$R^{-1} < k < \varepsilon \quad (6)$$

[independent fragmentation (IF) models^{11),12)}]. The reduction of this additional plateau is

$$(R\theta_0)^{-1} < k < \varepsilon \quad (7)$$

proves to be the major consequence of the coherence. It has been caught correctly by the string fragmentation (SF) model¹³⁾, actually. Needless to mention that both the LPHD approach and the Webber-Marchesini (WM) model¹⁰⁾ take this phenomenon fully into account.

To verify that the restriction (7) is intimately connected with PT coherence, let us represent the plateau distribution of particles from a gluon jet symbolically as follows:

$$dn = \frac{dk}{k} \frac{d\theta'}{\theta'} \cdot \delta(k\theta' - R^{-1}). \quad (8)$$

This expression can be thought of as a DL spectrum of bremsstrahlung (k, θ') from the gluon (ε, θ_0) , "projected" onto the domain of the most intensive radiation $(\alpha_s(k\theta')/\pi \sim 1)$ at the edge of PT. As is well known from PT analysis, the off-spring particles are independently emitted by the gluon only inside the cone with the opening angle

$$\theta' < \theta_0. \quad (9)$$

Applying this inequality to Eq. (8), one obtains restriction (7) at once.

Condition (7) reflects the fact that the hadron yield from bremsstrahlung depends rather on $p_{\perp} \approx \varepsilon\theta_0$ of a parent gluon than on its energy. Finally, the particle multiplicity can be written schematically as follows:

$$n = \int \frac{d\varepsilon}{\varepsilon} \int \frac{d\theta_0}{\theta_0} \delta(\varepsilon\theta_0 - R^{-1}) + \int \frac{d\varepsilon}{\varepsilon} \int \frac{d\theta_0}{\theta_0} \delta(\varepsilon\theta_0 - R^{-1}) \cdot \int \frac{dk}{k} \int \frac{d\theta'}{\theta'} \delta(k\theta' - R^{-1}). \quad (10)$$

Here the first term stands for the background quark plateau, the second one is constructed from the PT gluon emission (5), and fragmentation (8). The difference between the coherent and incoherent approaches has been encoded in Eq. (10) with the help of $\theta_{\max}$:

$$\begin{aligned} \theta_{\max}^{\text{incoh}} &= 1 && \text{for the incoherent case} \\ \theta_{\max}^{\text{coh}} &= \theta_0 && \text{for the coherent case} \end{aligned} \quad (11)$$

Now we are ready to deduce various differential distributions ρ , inserting

appropriate δ functions to fix K , $\Theta = \Theta_0 + \Theta'$ or $K_{\perp} = K\Theta$ of the registered particle. For the density of the energy "plateau" $\rho(K)$ our naive model gives:

$$\rho^{\text{incoh}}(K) = 1 + \mathcal{L}_s/2 (\ln^2 ER - \ln^2 KR) \quad (12.a)$$

$$\rho^{\text{coh}}(K) = 1 + \mathcal{L}_s \ln E/K \cdot \ln(KR). \quad (12.b)$$

The additional multiplicity $\int d \ln K (\rho(K)-1)$ appears to be twice as large for the incoherent case [this factor "2" exponentiates with an account of multiple branching¹⁵⁾]. Expressions (12) illustrate qualitatively the well-known fact that the coherence substantially depletes the soft part of the energy spectrum giving rise to a hump (see Fig.4a). For the rapidity (angular) distribution one obtains

$$\rho^{\text{incoh}}(\theta) = 1 + \mathcal{L}_s \cdot \ln^2(E\theta R) \quad (13.a)$$

$$\rho^{\text{coh}}(\theta) = 1 + \mathcal{L}_s/2 \cdot \ln^2(E\theta R). \quad (13.b)$$

Thus the rapidity spectra happen to be qualitatively similar, both demonstrating maxima ("d" shape) at $y_{\parallel} \approx 0$ (see Fig.4b).

Higher order analysis maintains this conclusion. Let us remind the reader that in the DL approximation, the angular distribution of particle flow in e^+e^- annihilation can be simply related to the derivative of the jet multiplicity $N'(E\theta)$ rising monotonically with θ ¹⁴⁾.

So, what is the origin of the two-humped b-spectra (b = Bactrian camel observed in experiments⁵⁾⁻⁷⁾? In the above consideration we assumed that the angle of multiplicity flow had been measured with respect to a fast particle (i.e., leading one) from a quark jet. The resulting d-spectrum thus corresponds to an inclusive two-particle angular correlation. Meanwhile the way of presenting experimental data in Fig. 3 is based on the widely used definition of a jet axis which is a totally exclusive characteristics of a hadron system, depending on the momentum of each particle in the event. This difference brings about the bias-effect: an energetic particle with large emission angle $\theta \sim 90^\circ$ (a candidate for $y_{\parallel} \approx 0$) causes the jet axis to shift, artificially depopulating the centre of the rapidity plateau (b spectrum).

The shape of the rapidity dip depends, naturally, on the concrete procedure used to determine the jet axis. This is clearly seen in Monte Carlo simulations¹⁰⁾.

One can risk sketching the energy evolution of the b-spectrum without appealing to Monte Carlo. Asymptotically the main contribution to the rapidity plateau density $\rho(y_{\parallel}) \sim N'(W/\text{ch}y_{\parallel}) \sim \sqrt{\alpha_s} N(W)$ comes from non-jet flow of soft hadrons which do not influence the jet axis. It is the parametrically smaller contribution of hard radiation $\sim \alpha_s N(W)$ that is pushed out from the region $y_{\parallel} \approx 0$ due to the bias. Therefore the dip should grow shallower (at least in relative scale) when W increases.

Let us outline the lessons from the "b-d" paradox: 1) a weight of prejudice which has arisen from the tradition of limited $p_{\perp}$ adversely affects the physical interpretation of the rising plateau; 2) the rapidity spectrum ($y_{\parallel}$) turns out not to be a one-particle inclusive characteristic (as the y spectrum is) being in essence a correlation. This fact implies that special care should be taken.

4. CONCLUSIONS

It looks intriguing that the shape of recently measured energy spectra of hadrons in e^+e^- annihilation appears to be unexpectedly close over the whole momentum range (down to momenta as small as $p \approx 200$ MeV to the MLLA predicted parton spectrum which contains no parameter except Λ . One can believe that such a similarity is indeed a manifestation of some deep intrinsic duality between parton and hadron systems, the nature of which should be explained by the future theory.

To verify the MLLA predictions more accurately, one needs an experimental separation of $e^+e^- \rightarrow q\bar{q}$ and $e^+e^- \rightarrow Q\bar{Q}$ events to be made. One can select the annihilation into light quarks ($q\bar{q}$) by triggering on a particle with sufficiently large momentum, so that it could not be the decay product of any leading hadron containing heavy Q ¹⁶⁾. Such a procedure ($x=2p/W > 0.7$) has been recently used by the HRS collaboration¹⁷⁾. Note that this event selection has not significantly changed the character of inclusive energy spectra. This observation justifies a posteriori the fitting of the whole data sample (without q - Q separation) by the MLLA formula for massless partons discussed in this paper.

On the other hand, of special interest is the study of the light hadron plateau in annihilation into heavy quarks $Q\bar{Q}$. The first TASSO results¹⁸⁾ have already shown the existence of a "reduced plateau"^{9),14)}. Its structure proves to be similar to that of the $e^+e^- \rightarrow q\bar{q}$ plateau with reduced total energy $E_{\text{eff}} \approx (1-\langle x \rangle_Q)E$, which accounts for the subtraction of a leading heavy hadron energy. Surely, new data in a wide energy interval and their comparison with light quark events at equivalent energies are necessary. It would be interesting also to observe the effect of widening of the angular distributions of light hadrons from $e^+e^- \rightarrow Q\bar{Q}$ as compared to $e^+e^- \rightarrow q\bar{q}$ ¹⁴⁾.

The essential difference in the structure of particle distributions over the total (i.e., energetic) rapidity y and the longitudinal one $y_{\parallel}$ turns out to be an important lesson. The understanding of this fact will help overcome prejudices originating from the old theory of strong interactions with limited transverse momenta.

Further important information about confinement may come from investigation of the jets in which hadron transverse momenta are bounded from above by some fixed value $p_{\perp \text{max}}$. Cutting off transverse momenta reduces PT parton cascades, thus illuminating the role of non-PT effects on particle content and distributions. The energy spectrum of hadrons from the reduced jet should lose its hump and approach the traditional flat plateau.

Investigation of the mass and quantum number dependence of hadron distributions will become the next step in the experimental physics of confinement. It aims at the classic question: what is the characteristic scale of space-time distances at which massive hadrons are formed? Recall that by bounding the relative $K_{\perp}$ of partons from below by the mass of the hadron registered ($K_{\perp} > Q_0 = M_h$) one obtains truncated PT cascades that give a reasonable over-all description of π , K and p energy spectra. Experiments with hadrons containing heavy quarks and, first of all, measurements of soft D, D^* , J/ψ , etc., distributions in jets from hadron colliders will become a source of further checks of the PT approach.

Present experiments give clear evidence of the efficacy of the PT picture of multiple hadroproduction - an approach exploiting asymptotic freedom intensively. It has predicted the hump-backed plateau and the approximate similarity of spectra of different hadrons, the rise of multiplicities and difference in properties of q and g jets, etc. It has also explained the origin

of KNO scaling in QCD jets and the collective character of hadroproduction (string-effect).

Experimental observations of such striking phenomena as the hump-backed plateau and string effect are showing quite convincingly that in spite of confinement the hadron system reproduces faithfully very delicate consequences of coherence reflecting the nature of QCD as a gauge theory. The close correspondence between parton and hadron systems in hard processes provides evidence in favour of the locality of colour neutralization and hadronization processes in configuration space.

The authors acknowledge fruitful discussions with D. Amati, I. Dyatlov, M. Jacob, L. Frankfurt, V. Gribov, B. Ioffe and A. Kaidalov.

R E F E R E N C E S

- 1) Ya.I. Azimov, Yu.L. Dokshitzer, V.A. Khoze and S.I. Troyan, Z.Phys.C - Particles and Fields 27 (1985) 65.
- 2) Yu.L. Dokshitzer and S.I. Troyan, in High Energy Physics (proceedings of the XIX LNPI Winter School), p.144, Leningrad (1984); preprint LNPI-922 (1984).
- 3) Ya.I. Azimov, Yu.L. Dokshitzer, V.A. Khoze and S.I. Troyan, in Physics and Elementary Particles (proceedings of XX LNPI Winter School), p.82, Leningrad (1985); preprint LNPI-1051 (1985).
- 4) Ya.I. Azimov, Yu.L. Dokshitzer, S.I. Troyan and V.A. Khoze, Yaf.Fiz. 42 (1985) N°.10, Physics Letters, to be published.
- 5) M. Althoff et al. (TASSO collaboration), Z.Phys.C. - Particles and Fields 22 (1984) 307; DESY preprint 84-093 (Sept. 1984).
- 6) A. Barbaro-Galtieri et al. (TPC collaboration), preprint LBL-18424 (1984); H. Aichara et al., Phys.Rev.Letters 52 (1984) 577; preprint LBL-18382 (1984).
- 7) D. Bender et al. (HRS collaboration), Phys.Rev. D31 (1985) 1.
- 8) D. Amati and G. Veneziano, Phys.Letters B83 (1979) 87.
- 9) Ya.I. Azimov, Yu.L. Dokshitzer and V.A. Khoze, in High Energy Physics (proceedings of the XVII LNPI Winter School), p.162, Leningrad (1982).
- 10) G. Marchesini and B.R. Webber, Nuclear Phys. B238 (1984) 1; B.R. Webber, ibid, p.492.
- 11) R.D. Field and R.P. Feynman, Phys.Rev. D15 (1977) 2590; Nuclear Phys. B138 (1978) 1.
- 12) T.D. Gottschalk, CERN preprint TH.3810 (1984).
- 13) B. Andersson, G. Gustafson, G. Ingelman and T. Sjöstrand, Phys.Reports 97 (1983) 33.
- 14) Yu.L. Dokshitzer, V.S. Fadin and V.A. Khoze, Z.Phys.C - Particles and Fields 15 (1982) 325; ibid. 18 (1983) 37.
- 15) B.I. Ermolayev and V.S. Fadin, JETP Letters 33 (1981) 285; A.H. Mueller, Phys.Letters B104 (1981) 161.
- 16) L.L. Frankfurt and V.A. Khoze, JETP Letters 23 (1976) 69; V.A. Khoze, Ya.I. Azimov and L.L. Frankfurt, in proceedings of the XVIII International Conference on High Energy Physics, Tbilissi, July 1976, Vol.II, p.B10.
- 17) M. Derrick (HRS collaboration), preprint ANL-HEP-PR-84-56 (1984).
- 18) M. Althoff et al. (TASSO collaboration), Phys.Letters B135 (1984) 243.

FIGURE CAPTIONS

Figure 1 : Hadron inclusive spectra in e^+e^- annihilation. All theoretical curves correspond to the universal expression (1) for $W = 29$ GeV [see Ref.1)].

- a) $\pi^\pm$, $K^\pm$, p ($\bar{p}$) spectra [note different scales for π and K , $p(\bar{p})$]. Full curves use the values of K^h as found in Ref. 1) to fit TASSO data⁵⁾ at $W = 34$ GeV. The dashed curve contains the additional strange meson suppression factor 0.73. Data are from TPC the collaboration⁶⁾ at $W = 29$ GeV.
- b) $\Lambda(\bar{\Lambda})$ spectra. Full curve accounts only for the higher mass of Λ hyperon ($K^\Lambda/K^p \approx 0.89$). The dashed curve contains also the strangeness suppression factor 0.28. Data are from TASSO at $W = 34$ GeV⁵⁾ and TPC at $W = 29$ GeV⁶⁾.

Figure 2 : Spectrum of all charged particles in e^+e^- annihilation at $W = 29$ GeV [HRS collaboration⁷⁾]. Dashed curves showing $\pi^\pm$, $K^\pm$, p ($\bar{p}$) contributions correspond to the curves in Fig. 1. The full curve is the result of summation of the contributions.

Figure 3 : Two-humped b-spectrum ("b"-Bactrian camel) in the distribution over the longitudinal rapidity $y_\parallel = \frac{1}{2} \ln (E+p_\parallel)/(E-p_\parallel)$, determined using the sphericity S axis (TPC data⁶⁾ at $W = 29$ GeV). The full curve is the one-humped d-spectrum ("d" dromedary), where the rapidity is calculated using the direction of the leading particle in the jet.

Figure 4 : The effect of coherence on energy, angular and $k_\perp$ distributions. Dotted areas correspond to the contribution which is removed when turning from the incoherent model (dashed) to the coherent one (solid curve). Shaded areas show the old-fashioned plateau (without taking account of bremsstrahlung).

Fig. 1a

Fig. 1b

Fig. 2

Fig. 3

Fig. 4