BRIEF REVIEW ON JET UNIVERSALITY

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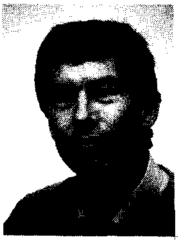


ABSTRACT:

Hadron-hadron collisions are compared to lepton-hadron and e^+e^- collisions under the assumption of partons acting as basic fields in all three. In this comparison, more significance is attached to differences observed in various types of correlation rather than to previously observed similarities in more simple-minded distributions. A number of non-trivial differences exist between e^+e^- and lh (hard) collisions on one side and (soft) hadronic collisions on the other. Within a "dynamical" universality of similar color dipole or chain fragmentation in all types of collision, hadron-hadron collisions necessitate a number of chains, some with large angles relative to the others.

I. INTRODUCTION

The concept of "jet universality" is based on early observations of a similarity of particle production in e^+e^-, deep inelastic lepton-hadron, and hard as well as soft hadron-hadron collisions.

This "naive" universality could not be maintained at closer inspection. Diquarks were found to lead to lower average multiplicity $\langle n \rangle$ than quarks, with $\langle n \rangle$ growing slower with the hadronic mass W than that of quark jets[1-3], but it did not seem to matter whether these quarks and diquarks were excited in lh or hh collisions. Similar differences between quark and diquark jets were found in the dispersion D.

In the following we want to show on a number of topics that also this "learned" universality cannot be maintained. It has to be replaced by a "dynamical" universality of (multiple) chain or colour dipole fragmentation.

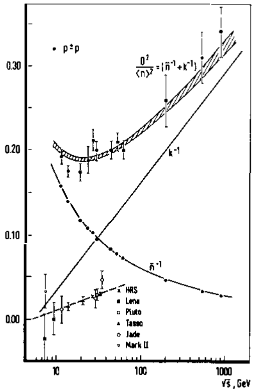
II. NEGATIVE BINOMIALS

A parameter particularly sensitive to differences in hard and soft collisions turns out to be the parameter k of the negative binomial form[4-6] recently used[7] to describe multiplicity distributions up to collider energies. In fig.1 we reproduce 1/k as obtained by the UA5 Collaboration for non single-diffractive $p^{\pm}p$ data from $\sqrt{s}$=10-900 GeV and compare it to 1/k obtained from fits to published e^+e^- multiplicity distributions from 7-35 GeV[8-13]. Clearly, 1/k is lower and rizes more slowly with $\sqrt{s}$ for e^+e^- collisions than for $p^{\pm}p$ collisions.

To see whether the difference between $pp^{\pm}$ and e^+e^- is due to a typical hh effect or simply due to the quark-diquark difference discussed above, meson-proton (M^+p) data[14] are compared to μp[2] and pp data in fig.2. The solid line (with a slope of 0.058) in both sub-figures corresponds to 1/k for $p^{\pm}p$ of fig.1. The pp data of fig.2a and the M^+p data in fig.2b roughly follow the line (for the small difference between pp and M^+p data see ref.15).

On the other hand, the μp data expected to be similar to M^+p data from "learned" universality, instead follow the trend of the e^+e^- data. The corresponding slopes of the dashed line fits are 0.023±0.007 for μp and 0.016±0.003 for e^+e^- collisions. We have to conclude, that (soft) hh collisions show a 1/k behavior different from that of (hard) e^+e^- and lh collisions.

In fig.3a,b) one can see for $p\bar{p}$[16] data and e^+e^-[13] data, that negative binomials also give perfect fits to the multiplicity distributions for rapidity intervals around the center. In both cases, k increases with the size of the interval. At $y \approx 0$, k is equal for M^+p and pp collisions at the same energy[15], but different for e^+e^- collisions. It would be important to see the values for μp data.



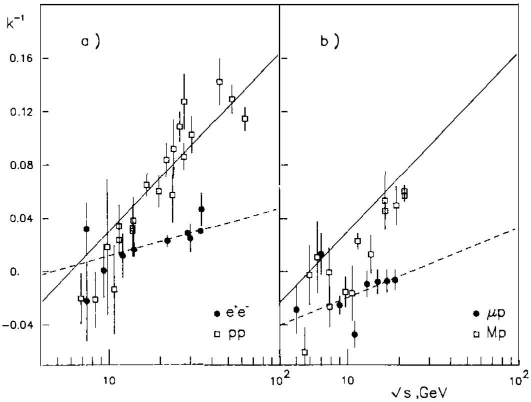


Fig.1 Parameters $\bar{n}^{-1}$ and k^{-1} for negative binomials and $D^2/\langle n\rangle^2$ for $p^{\pm}p$ data[7] and k^{-1} for e^+e^- data[8-13], as a function of $\sqrt{s}$.

Fig.2 The parameter k^{-1} from a) fits to n>6 pp data and n>2 e^+e^- data, b) to n>6 $M^{\pm}p$ and to μp data. The solid line is that from fig.1. The dashed lines are linear fits to the e^+e^- and μp points, respectively[14].

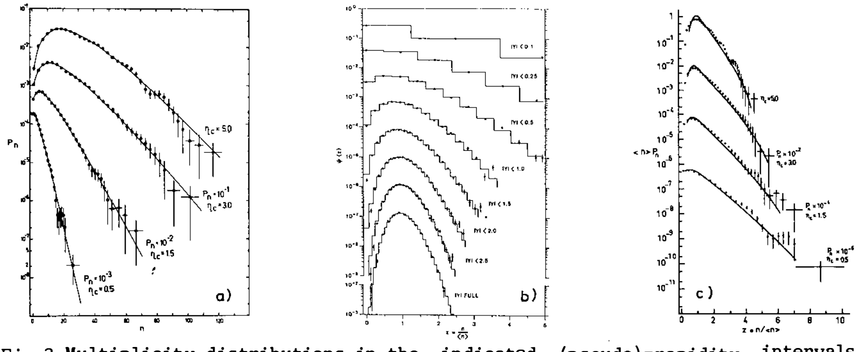


Fig.3 Multiplicity distributions in the indicated (pseudo)-rapidity intervals for $p\bar{p}$ collisions at 540 GeV (fig.3a,c)[16] and e^+e^- collisions at 29 GeV (fig.3b)[13]. The solid lines in figs.3a,b are negative binomial fits, in fig.3c DTU predictions[20].

What do models tell us about the above observations? From fig.1 one can see that at large energies $D^2/\langle n\rangle^2$ is rising with energy due to the increase of 1/k. KNO scaling [18] predicts $D^2/\langle n\rangle^2$ to be independent of energy and is therefore excluded for hh collisions in the full rapidity region.

A beautiful comparison of the two classes of (partially) stimulated emission and cascade models is performed in ref.[6]. Experimentally, stimulated emission can now probably be excluded from k values being larger for negatives than for all charged particles[15].

The Lund model as it stands[18] gives too narrow multiplicity distributions for hh collisions, even at low energies. However, an interesting new two-chain Lund model (LUND '86) with gluon emission[19] remains to be tested. Closer to negative binomials come the predictions from the DTU model[20], even though the simple functional form itself cannot be derived from the model. In Fig.3c, a comparison with the UA5 data is shown. The bare prediction is still slightly too narrow. There may be room for another mechanism.

More fundamentally, Malaza and Webber[21] derive QCD predictions for the first five moments of the multiplicity distribution, and find that they are close to those of a negative binomial distribution.

For further discussion of this challenging and quickly developing topic see refs.[16)22-25].

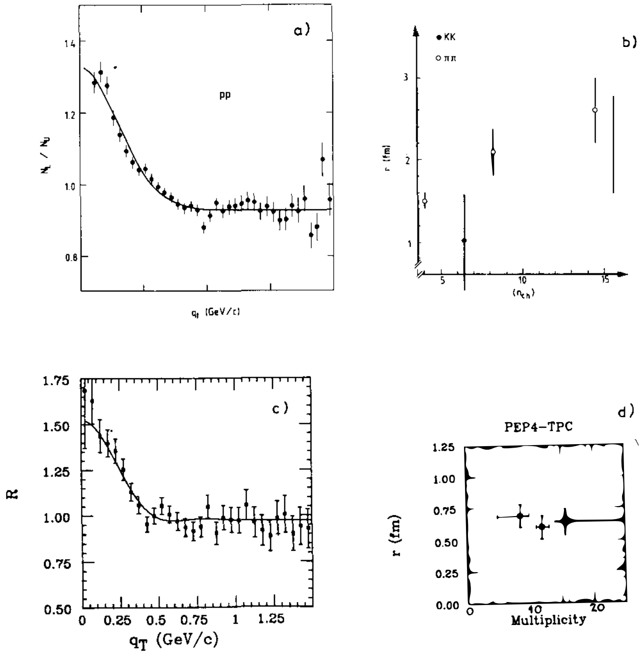


Fig.4 a) The q_t distribution for like charge pairs divided by unlike pairs for pp collisions at $\sqrt{s}$=63 GeV[28], b) the radius r as a function of the charge multiplicity at $\sqrt{s}$=53 and 63 GeV[27], c) the q_t distribution for like pairs divided by uncorrelated background and d) r as a function of the multiplicity for e^+e^- collisions at 29 GeV[29]. The solid lines are fits to a Bessel function in $q_t r$.

III. BOSE-EINSTEIN CORRELATIONS

An interesting difference between $p^{\pm}p$ and e^+e^- collisions can be observed in the multiplicity dependence of the size of the meson emitting region. The radius r and an incoherence λ can be estimated from the correlation of two identical bosons at small (transverse) distances q_t in momentum space[26].

Recent measurements of the radius r in $\alpha\alpha$, pp and $p\bar{p}$ collisions come from the AFS[27] and SFM[28] (fig.4a) collaborations. In both cases, r is slightly larger than 1fm and the incoherence is $\lambda \approx 0.5$. The AFS collaboration observes a dependence of r on n, as shown in fig.4b. In high multiplicity events, the bosons appear to originate from a larger space-time region.

For e^+e^- collisions, Bose-Einstein correlations have been measured by TPC[29] (fig.4c) and TASSO[30]. Using the same (spherical) parametrization as in the ISR experiments grants similar r and λ as for $pp^{\pm}$ collisions. However, here r does not depend on n (fig.4d).

Introduction of Bose-Einstein correlations into existing string models looks quite natural and good results have already been obtained for e^+e^- collisions[31].

IV. TRANSVERSE MOMENTUM DEVELOPMENT

A handy distribution to trace hard effects is $\langle p_t \rangle$ or $\langle p_t^2 \rangle$ versus x (the "sea-gull"). Neutrino experiments[32][33] have shown that already at W<10GeV the sea-gull is lifting its wings, in particular the current fragmentation wing, as W increases. Fig.5a gives the sea-gull for μp collisions[34] ($40 < W^2 < 400$ GeV^2) compared to the Lund model[35] with standard three-jet parameters (solid curve), no three-jet events (dashed), no soft gluons (dot-dashed) and no soft gluons but $\langle k_t^2 \rangle = (0.88 \text{ GeV})^2$ (dotted). According to this parametrization, soft and hard gluons seem responsible for the high $\langle p_t^2 \rangle$ values.

A very similar behavior is observed for e^+e^- annihilation[12] (fig.5b). The narrower jet has little energy dependence, while the wider jet shows rapid increase of $\langle p_t^2 \rangle$ with energy. The curve corresponds to a QCD independent jet fragmentation model[36], but predictions from the three-jet string model are similar[37].

However, a rise of the sea-gull wings is also observed in hh collisions! Like for lh collisions, this rise has been observed already at lower energies[38-40] and is now seen[41] to persist at $\sqrt{s} \approx 22$ GeV (fig.5c). Here, the increase is visible in both wings and may be the onset of hard parton scatters and/or gluon emission. In fig.5d, the standard low-p_t Lund model[18] cannot reproduce the effect.

At higher energies, the increasing importance of the intermediate p_t region is observed in the form of "mini-jets" [42][43]. These are defined with the UA1 jet-finding algorithm as jets with transverse energy $E_{Tj} > 5$ GeV and an axis with

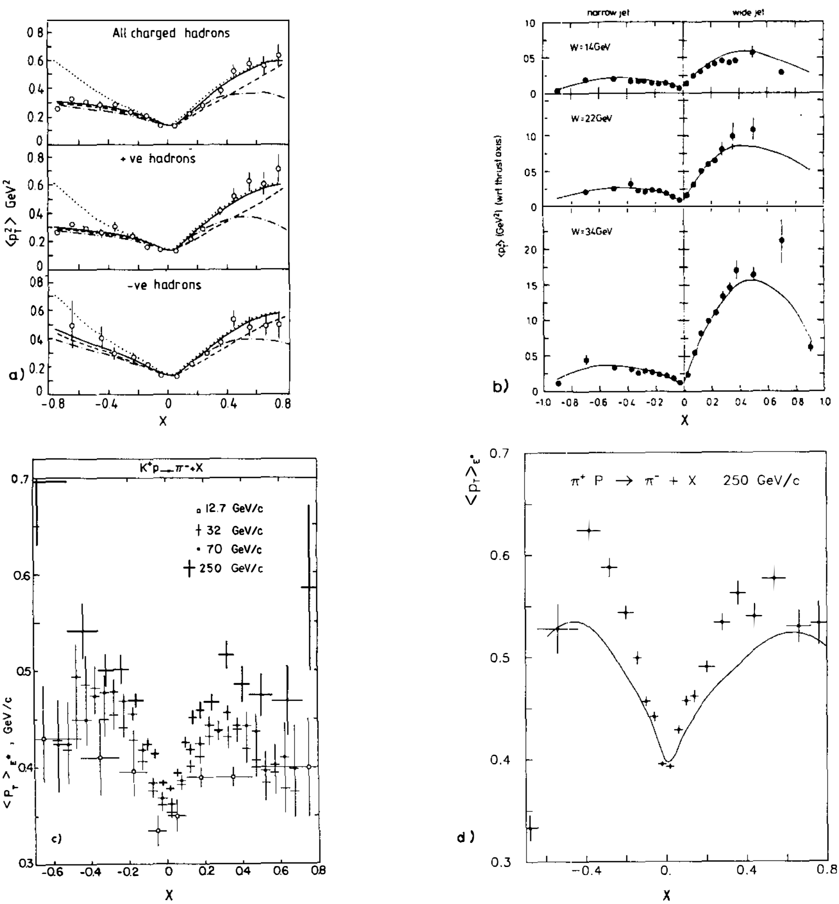


Fig.5 Values of $\langle p_t^2 \rangle$ as a function of x for a) μp collisions[34] with $40 < W^2 < 400$ GeV^2, b) e^+e^- data[12] with respect to the thrust axis (the curves are described in the text). Values of $\langle p_t \rangle_{E^*}$, weighted by phase space for c) $K^+p \to \pi^-X$ from 12.7 to 250 GeV/c and d) $\pi^+p \to \pi^-X$ at 250 GeV/c[41] compared to standard low-p_t Lund.

$|\eta| < 1.5$ and azimuth angle $> 30°$ from the vertical. The acceptance corrected fraction of events containing at least one mini-jet (semi-hard component) increases roughly logarithmically from 12% at 200GeV to as much as 35% at 900GeV.

Events without mini-jets (soft component) is characterized by low $\langle n \rangle$, large D and low $\langle p_t \rangle$, the semi-hard component by large $\langle n \rangle$, small D and high $\langle p_t \rangle$. As shown in fig.6 for 200 and 900 GeV, the n dependence of $\langle p_t \rangle$ is much less pronounced for the semi-hard component than for the soft component.

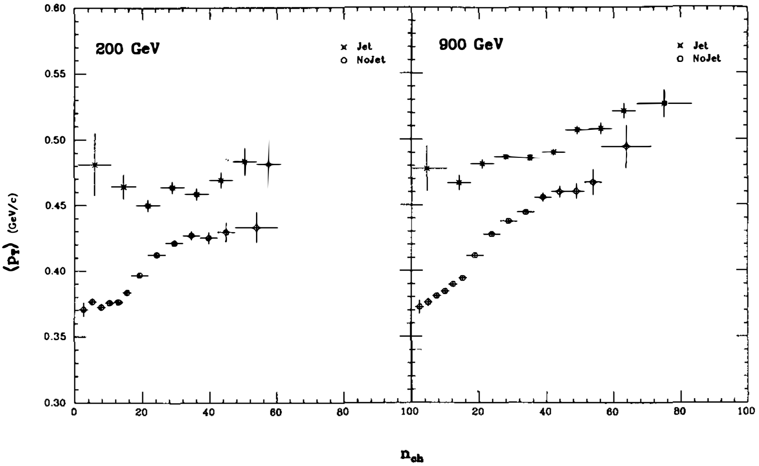


Fig.6 Average transverse momentum as a function of the event charged multiplicity for no-jet and jet samples at 200 and 900 GeV[42].

The development of low-p_t models in the direction of semi-hard effects is well on its way. LUND'86[19] has the flexibility of both of a rotation of the two color dipoles with respect to each other and/or of gluon radiation within the dipoles. These options may be enough to explain the increase of $\langle p_t \rangle$ in the sea-gull wings at fixed-target energies.

At the collider, more chains seem to be needed as they appear in DTU[44][45]. Bopp et al.[45] compare two classes of models within DTU, one where gluon emission induces large fluctuations in the parent parton transverse momentum, the other where partons acquire transverse momentum via a hard scattering. They find that both approaches describe the data equally well, and that the transition from soft to semi-hard processes is a smooth one.

V. AZIMUTHAL CORRELATIONS

An important question in hadronization is short range order from $q\bar{q}$ pair production. Studying this from non-strange mesons is hampered by the $q\bar{q}$ combinatorial background. What is needed is a flag identifying the pairs having been created together. Because of the strange sea suppression, there is less combinatorial background for $s\bar{s}$ pairs and this flag does indeed exist, there.

For e^+e^- annihilation good strangeness identification is available in the TPC detector at $\sqrt{s}$=29 GeV. This collaboration observes[46] significant short range K^+K^- correlations in y. It is well reproduced by the Lund model[18] and by the Webber QCD model[47].

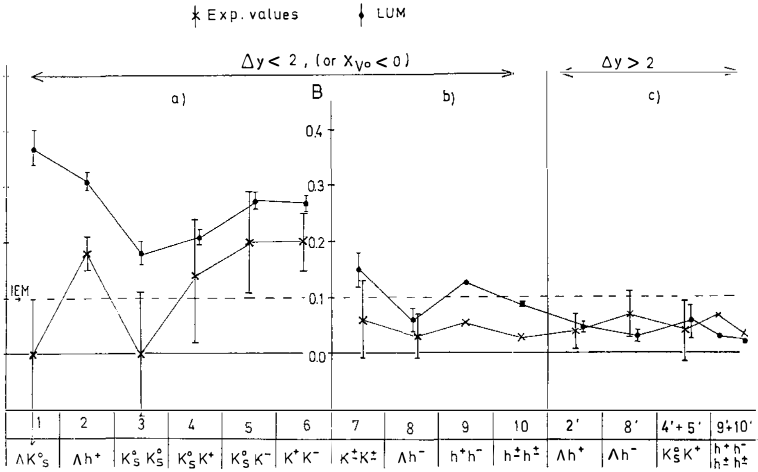


Fig.7 Asymmetry parameter B for the indicated particle pairs at $\Delta y<2$ (figs.7a,b) and $\Delta y>2$ (fig.7c)[51].

A more stringent test than the associated strangeness density used above is the azimuthal angular correlation $\Delta\Phi$ between the transverse momenta of pairs of strange particles[48] as a function of Δy. For $\Lambda\bar{\Lambda}$ pairs, azimuthal correlation has been observed in MARKII at 29 GeV[49]. Similar K^+K^- correlations are seen in the exclusive hh final state $K^-p\rightarrow pK^+K^-K^-\pi^+\pi^-$ at 32 GeV/c[50].

The results of a systematic study of the $\Delta\Phi$ correlation in pp collisions at 360 GeV/c[51,52] are given in fig.7. There, the asymmetry parameter $B = [N(\Delta\Phi>\pi/2)-N(\Delta\Phi<\pi/2)]/N_{all}$ is given for pairs with (a) opposite strangeness and small Δy, (b) same strangeness and small Δy and (c) same or opposite strangeness, but large Δy. In general, class (a) has larger asymmetry B than the expectedly uncorrelated classes (b) and (c), and larger B than expected from independent emission (dashed line). However, the asymmetry for class (a) (and also (b)) pairs is <u>smaller</u> than expected from the standard Lund model.

The azimuthal correlation can of course also be studied for $c\bar{c}$ in $D\bar{D}$ production. An asymmetry has indeed been observed in π^-p collisions at 360 GeV/c[53]. Also there, the Lund model overestimates the effect.

We believe that the overestimation of B in Lund is related to the underestimation of the height of the sea-gull wings.

VI. POLARIZATION

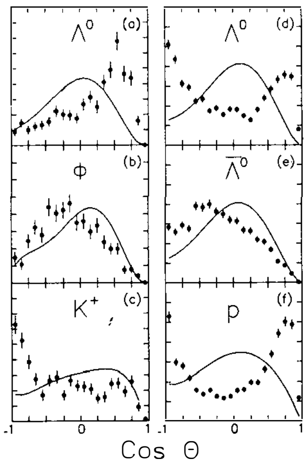
A particularly interesting difference between hh, lh and e^+e^- collision is to be expected in hyperon polarization. While the previous comments were on typical hadronization properties, polarization is at least partially determined by the production (excitation) mechanism on the parton level.

Because of space limitation I have to refer to my comparison in ref.[54]. Here, I just want to say that the available data on hyperon polarization show the differences expected for hh, lh and e^+e^- collisions, but a more differential study in higher statistics data would be welcome for the latter two.

VII. DIFFRACTION DISSOCIATION

So far, we were mainly concerned with a comparison of e^+e^-, lh and non-diffractive hh collisions. An important question left is that of diffractive hadron production. Is the decay of the diffractively excited system more or less isotropic or is it elongated like a fragmentation chain?

The R608 Collaboration[55] has studied the exclusive channels $pp \to (\Lambda^0 \phi K^+)$ p and $pp \to (\Lambda \bar{\Lambda}^0 p)$ p at $\sqrt{s}$=63 GeV, with the bracketed system carrying momentum near that of the beam. A difference from isotropic decay is clearly observed in the Gottfried-Jackson angular distribution of the decay products in fig.8. The Λ^0 which can carry a ud diquark of the beam proton, is peaked in the direction of that proton in fig.8a. In fig.8c), the K^+ probably carrying the remaining u quark is peaked in the opposite direction. The ϕ does not carry any proton valence quark and is more central (fig.8b).



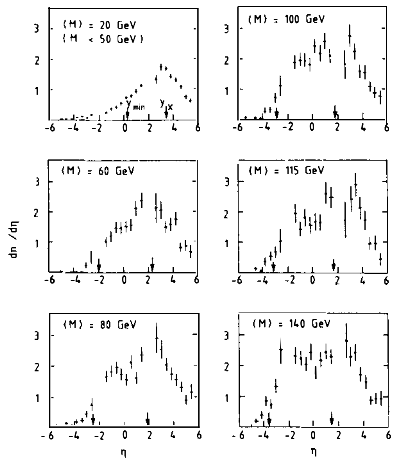


Fig.8 Gottfried-Jackson angular distribution of the particles indicated in the diffractively produced forward system of pp collisions at $\sqrt{s}$=63 GeV[55]. The solid lines correspond to isotropic phase space events passed through the acceptance of the apparatus.

Fig.9 Pseudorapidity distributions of charged tracks from the fragmentation of diffractive states of average mass ⟨M⟩ as indicated, at $\sqrt{s}$=546 GeV. The arrows show the expected position of the center of the cluster and that of the inner edge[64].

The above observation is in agreement with the idea[56] of pointlike pomeron-quark coupling. This leads to the back-scattering of one quark in the proton with a continuing spectator diquark as in deep-inelastic scattering (for earlier thoughts in this direction see refs.[57][58]). The consequent elongation of the diffractively produced system along the pomeron-proton collision axis is observed in the exclusive final states $pp \to (p\pi^+\pi^-\pi^+\pi^-)\,p$ by the same collaboration[59] and at 360 GeV/c[52] and earlier in $\gamma p \to (\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-)\,p$ by the Omega Photon Collaboration[60]. The hadronization of the diffractive system is well described by a Lund string[59][61] similar to that of lh collisions.

Early results on inclusive diffraction dissociation[62,63] derived from (pseudo-) rapidity distributions were inconclusive. At collider energies, however, a rapidity plateau develops[64] at the highest diffractive masses (see fig.9). The central rapidity density of the diffractive cluster rises with the excitation mass M in a way very similar to the rise of that in non-diffractive events with $\sqrt{s}$ (not shown). The same holds for $\langle n \rangle$ compared to that for non-diffractive events. The results can be reproduced[65] within DTU, where chains are stretched between valence constituents of the excited proton and sea constituents of the non-excited one.

But what about $q\bar{q}$ systems? They are simpler than q(qq) systems and more straight-forward to compare to e^+e^- results. The obvious place is to look in high energy meson diffraction dissociation. There, the disadvantage of the relatively low energy is compensated by the increased rapidity range on one hand, and the availability of very differential data on the other.

The NA22 Collaboration[66] separates the inclusive single diffractive

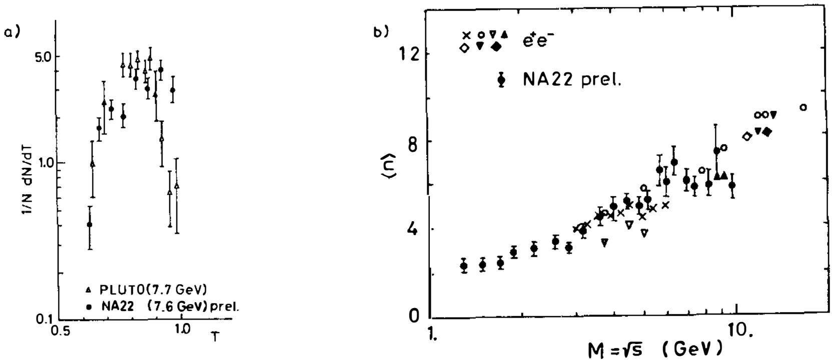


Fig.10 a) Thrust distribution for K^+ diffractive dissociation at 250 GeV/c[66] compared to that of e^+e^- events at the corresponding energy[67], b) effective mass dependence of the average multiplicity in K^+ dissociation and e^+e^- collisions.

component by a combined rapidity and rapidity gap method. In fig.10a we compare preliminary results for the thrust distribution of the K^+ diffractive system (with average excitation mass of 7.4 GeV) to PLUTO data[67] at 7.7 GeV. One can see that the diffractive system is at least as elongated along the thrust axis as the e^+e^- data. Fig.10b shows the excitation mass (respectively $\sqrt{s}$) dependence of $\langle n \rangle$ for the diffractive system and for e^+e^- collisions (both including charged pions from K^0_S decays). The agreement justifies further investigation.

VIII. SUMMARY AND CONCLUSIONS

Hadron-hadron collisions have been compared to lepton-hadron and e^+e^- collisions under the assumption of partons acting as basic fields in all three. In this comparison, more significance has been attached to differences observed in correlations rather than to previously observed similarities in simpler distributions. The results are summarized in the following table:

Effect	e^+e^-, lh		(soft) hh	Models
Neg. Binomials	$e^+e^- \approx \mu p$	$\neq$	$M^+p \approx pp$	
$1/k$ vs. $\sqrt{s}$	small and flat	$\neq$	large and steep	stimul. em., casc.
k at y=0	large	$\neq$	small	- " -
k vs. Δy	rapid increase	$\neq$	slow increase	DTU?
negatives	?		$k^- > k^{ch}$	stimul. em. out
Bose-Einstein				
r	> 1 fm	$\approx$	> 1 fm	easy to incorporate,
n dependence	no	$\neq$	yes	first results in
λ	≈ 0.5	$\approx$	≈ 0.5	string models
p_t development				
"sea-gull"	wings rise	$\approx$	wings rise	hope in Lund, DTU
"mini-jets"			yes	DTU
p_t correlations	yes	>	yes	for hh too strong
Polarization				
Λ	e^+e^- : no	$\neq$	transverse	as expected
	lh : longit.		(rise with p_t)	
Diffraction			meson $\approx e^+e^-$	P-Υ analogy
			proton $\approx$ lh	Lund '86, DTU

A number of non-trivial differences exist between e^+e^- and lh (hard) collisions on one side and (soft) hadronic collisions on the other. Within a "dynamical" universality of similar color dipole or chain fragmentation in all types of collision, hadron-hadron collisions necessitate a number of chains, some with large angles relative to the others.

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