SELECTED TOPICS ON (ULTRA-)SOFT EFFECTS

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ABSTRACT

Factorial correlators are studied in 250 GeV/c π^+p and K^+p collisions as a function of the distance in rapidity. The correlators are found to increase with decreasing correlation distance, independently of the rapidity resolution. The increase approximately follows a power law, but the power is considerably larger than expected from a log-normal approximation in the simple α model of intermittency. Also the FRITIOF results are independent of the resolution, but slopes and p_T behaviour cannot be reproduced by this model.

Inclusive production of direct soft photons is studied in K^+p and π^+p interactions at 250 GeV/c. Total cross sections, Feynman-x and transverse momentum distributions of direct γ's are presented. The measured cross sections are several times larger than expected from QED inner bremsstrahlung, indicating the presence of an anomalous soft photon source. The model of Lichard and Van Hove, based on a "cold quark-gluon plasma" picture, agrees with the data.

In hadron-hadron collisions, the K/π ratio increases with increasing energy, increasing multiplicity n, increasing transverse momentum p_t, but not with increasing transverse mass m_t. The strange quark suppression factor λ_s, furthermore, is larger in the central than in the fragmentation regions.

1 Factorial Correlators

Intermittency[1] has now been studied in e^+e^-, μp, νA, hadron-hadron, hadron-nucleus and nucleus-nucleus collisions, and has beautifully been reviewed at this Rencontre by B. Buschbeck[2]. The study has been performed in terms of a power law dependence of the scaled factorial moments

$$\langle F_i \rangle = \frac{1}{M} \sum_m \frac{\langle n_m(n_m-1)\dots(n_m-i+1)\rangle}{\langle n_m \rangle^i} \quad , \tag{1}$$

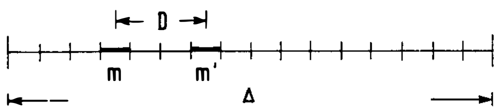
where M is the number of phase-space bins of size $\delta = \Delta/M$ into which an original region Δ is subdivided, n_m is the multiplicity in bin m ($m = 1, \dots, M$). The averages under the sum are over the events in the sample.

While in the early stage of the analysis the interest mainly arose from the difficulties of currently used models to reproduce the effect, recent e^+e^- results are reproduced by a number of models and a number of alternative attempts exist to explain the residual effect in the other types of collisions. These range from conventional short range correlations and Bose-Einstein interference, via pencil jets and extended parton cascades, to a possible signal for quark-gluon-plasma. Different data support different interpretations, so that more discriminative information is needed experimentally.

While the moments defined in (1) measure local density fluctuations in phase space, additional information is contained in the correlation between these fluctuations within a given event. This correlation can be extracted by means of the factorial correlators[1]

$$\langle F_{ij}^{mm'} \rangle = \frac{\langle n_m(n_m-1)\dots(n_m-i+1)\; n_{m'}(n_{m'}-1)\dots(n_{m'}-j+1)\rangle}{\langle n_m \dots (n_m-i+1)\rangle \langle n_{m'} \dots (n_{m'}-j+1)\rangle} \quad , \tag{2}$$

where n_m is the multiplicity in bin m and $n_{m'}$ that in bin m'. The correlators are calculated at given δ for each combination mm' and then averaged over all combinations with given D, as shown below.



According to a simple intermittency model (α-model)[1], the $\langle F_{ij} \rangle$ should depend only on D and not on δ, and the dependence should be according to the power law

$$\langle F_{ij} \rangle \propto (\Delta/D)^{f_{ij}} \quad . \tag{3}$$

For the power f_{ij} (slope in a log-log plot) the following relation has been derived:

$$f_{ij} = f_{i+j} - f_i - f_j = ij f_2 \quad , \tag{4}$$

where the first equal sign is due to the α model, the second to the log-normal approximation.

Preliminary results for pseudo-rapidity resolution $\delta\eta \geq 0.4$ have been reported by the HELIOS Collaboration[3], where, however, the multiplicities had to be estimated from the transverse energy. New results come from the NA22 experiment[4] for the resolution $\delta y \geq 0.1$. The $\ln\langle F_{ij} \rangle$ are shown as a function of $-\ln D$ in Fig.1a-d, for four values of δy, respectively.

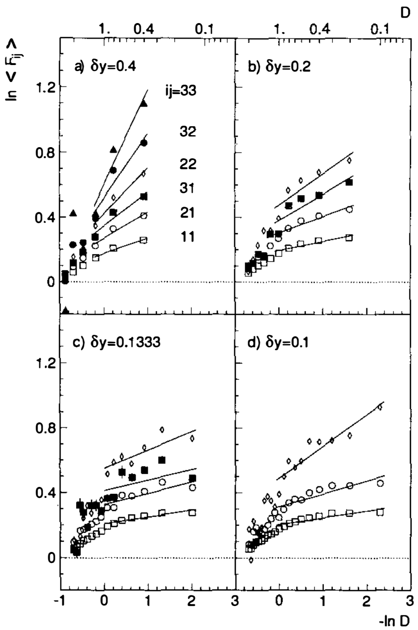


Fig. 1

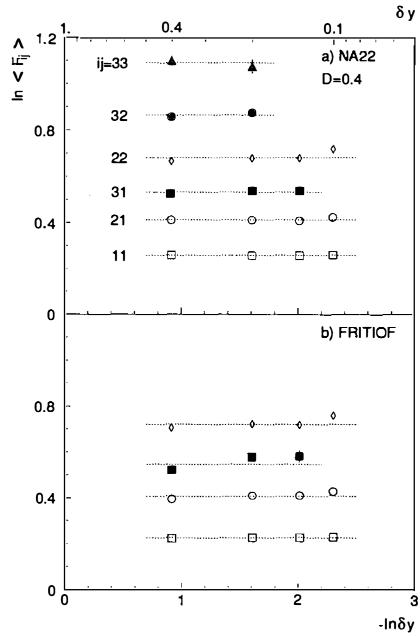


Fig. 2

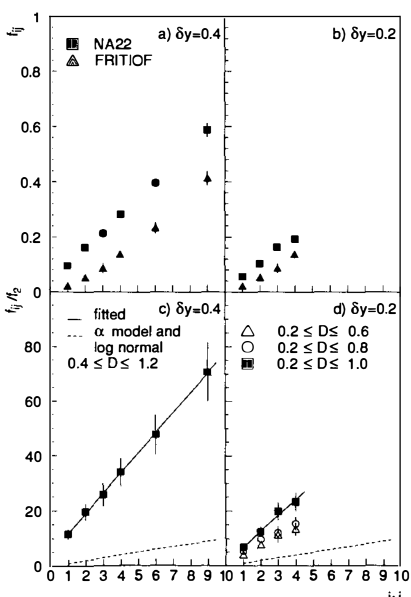


Fig. 3

Fig.1 $\ln\langle F_{ij}\rangle$ as a function of $-\ln D$ for four values of δy, as indicated.

Fig.2 Dependence of $\ln\langle F_{ij}\rangle$ on the bin size δy for a correlation distance $D = 0.4$,
a) for NA22 data, b) for a sample of 60 000 FRITIOF Monte Carlo events. The dashed lines correspond to horizontal line fits through the points.

Fig.3 a) b) The increase of the slopes f_{ij} with increasing order ij compared to the expectation from FRITIOF, for two values of δy, respectively; c) d) the increase of f_{ij}/f_2 with increasing order ij, compared to that expected from the α model (dashed line), for two values of δy, respectively.

In all cases an increase of $\ln\langle F_{ij}\rangle$ is observed with increasing $-\ln D$.

In Fig.2a) the $\ln\langle F_{ij}\rangle$ at fixed D=0.4 are compared for the four different values of δy. As expected from the α model, the $\langle F_{ij}\rangle$ indeed are independent of δy. However, this property is not unique to the α-model. Fig.2b shows that the δy independence is also reproduced by the FRITIOF model[5] and is probably common to any model with short-range order.

For $\langle F_{11}\rangle$, the δy independence can be extracted from the integral over the two-particle density, with two integration domains of size δy separated by D. Using exponential short range order[6], this gives

$$\langle F_{11}\rangle - 1 \quad \propto \quad \frac{1}{a^2} e^{-D/L} \cdot (e^a - 1)(1 - e^{-a}) \tag{5}$$

where L is a correlation length and $a = \delta y/L$. According to (5), $\langle F_{11}\rangle$ becomes independent of δy for $a < 1$. Since $e^{-D/L} \to 1$ with $D \to 0$, this form also leads to the deviations from (3) observed as a bending in Fig.1.

Because of the bending, fitted slopes f_{ij} only can be used as an indication for the increase over a certain range. For two values of δy they are compared to FRITIOF predictions in Fig.3a) and 3b), respectively. As already observed for single moments, the FRITIOF increase is too slow also for the correlators $\langle F_{ij}\rangle$. This shortcoming is related[6] to the failure of the model to reproduce the two-particle rapidity correlations in the same[7] and other data[8]. Future improvements of the model should account for these results simultaneously.

According to (4), the ratio f_{ij}/f_2 is expected to grow with increasing orders i and j like their product ij. In Figs.3c) and 3d) this is tested for δy=0.4 and δy=0.2, respectively. In both cases, the experimental results lie far above the dashed line corresponding to the expected $f_{ij}/f_2 = ij$. Since the dependence of $\ln\langle F_{ij}\rangle$ on $-\ln D$ is not strictly linear, the comparison depends on the range of δy and D used to determine f_2 and f_{ij}. In Fig.3d), therefore, a number of fits are compared. Slopes are reduced when reducing the upper limit in D, but do not reach the α-model prediction (dashed line).

A convincing explanation for the violation of expectations (3) and (4) is given by Peschanski and Seixas[9], also reported here. Agreement can be restored from a 3 dimensional intermittency ansatz. Furthermore, a projection independent scaling relation can be derived and shown to hold for the NA22 data. The multi-dimensional ansatz closes the circle with recent conjectures of W. Ochs[10] and Białas and Seixas[11] discussed here by Buschbeck[2].

2 Anomalous Sources of Soft Electromagnetic Radiation

Over the past decade experiments have found persisting evidence for anomalous sources of electromagnetic radiation in hadron-hadron collisions. Electron production at low p_T is more abundant than expected from known origins, including hadronic bremsstrahlung and charmed particle decays. A dilepton (e^+e^- and $\mu^+\mu^-$) continuum of masses well below 600 MeV/c^2 is measured, up to two orders of magnitude larger than estimated from the Drell-Yan process. The ratio of prompt e^+ to π production in the rapidity region $|y| < 1$ and $p_T < 0.4$ GeV/c rises approximately linearly with n_{ch}, the charged particle multiplicity of events, indicating that the production rate is proportional to n_{ch}^2. A possible explanation is "soft annihilation" where lepton pairs are created through annihilation of quarks and antiquarks produced during the collision. Alternative explanations are based on thermodynamic models (see ref.12 for a list of references on this topic).

Sea-quark annihilation into virtual photons, observed as lepton pairs, implies that soft real photons must also be produced in the same collision. The first evidence for a direct soft photon signal comes from a π^+p experiment at 10.5 GeV/c beam momentum[13]. There, the signal was found to be compatible with hadronic inner bremsstrahlung. However, an excess of direct soft photons, four times larger than expected from this last process, has been measured in K^+p collisions at 70 GeV/c [14].

More recent results of AFS[15] exclude a strong increase of the γ signal beyond that observed in[14]. Preliminary data from the HELIOS Collaboration[16] show a prompt-γ signal in the central rapidity region for $p_T < 30$ MeV/c in p Be and p Al collisions at 450 GeV/c. The signal may, however, be compatible with that expected from known sources. A clear excess of direct soft photons is seen by the EMC Collaboration in μp interactions at 200 GeV/c[17]. The anomalous effect is, therefore, not restricted to hadron collisions. This indicates that a phase transition from hadronic to quark matter is unlikely to be the origin.

The mechanism behind these soft phenomena is at present far from understood[18]. In the limit of very small p_T, the wavelength of the photons is large compared to the hadronic interaction region. Processes confined within this region with a typical size and lifetime of 1 fermi should not contribute. This was verified by B. Andersson et al.[19] using the space-time structure of the Lund string fragmentation model. Much larger scales, of the order of several to tens of fermi, seem to be involved.

Recently, three models have been proposed to explain the soft photon puzzle by non-standard mechanisms. The model by Barshay[20] is based on a "pion condensate", that by Shuryak[21] on a "pion liquid" picture. Lichard and Van Hove[22] suggest that this and other "ultrasoft" effects may find a common explanation in the formation of dense "globs" of cold partonic matter at the end of a QCD cascade, soft photons being produced via gluon Compton scattering and quark-antiquark annihilation in lowest order QED and QCD.

New results on prompt soft photon emission are reported for $M^+p \to \gamma + X$ ($M^+ = K^+$ or π^+) at 250 GeV/c [23]. The distribution in Feynman-x of direct soft γ's (Fig.4) is determined using, on the one hand, FRITIOF for non-π^0 decays, and the properties of the $\pi^0 \to \gamma\gamma$ decay kinematics for the dominant π^0 contribution, on the other hand. The spectrum at 250 GeV/c is similar in shape to that measured in 70 GeV/c K^+p collisions[14], also shown in Fig.4a. The QED hadronic inner bremsstrahlung contribution to direct soft photons (full line) lies systematically below the data, although its shape is quite similar. The dashed histograms in Fig.4 are predictions by Lichard and Van Hove[22] derived in the "cold-quark gluon plasma" (CQGP) model. The agreement with the NA22 data is quite remarkable.

To extract the prompt photon cross section as a function of transverse momentum, FRITIOF is used for background simulation. The model reproduces well the $d\sigma/dp_T$ distribution, except at very small p_T. The remaining signal is plotted in Fig.5. The dashed histograms show the CQGP-model predictions. They agree well with the data. In contrast, the inner bremsstrahlung cross section (full line) is several times smaller than the measured direct photon signal.

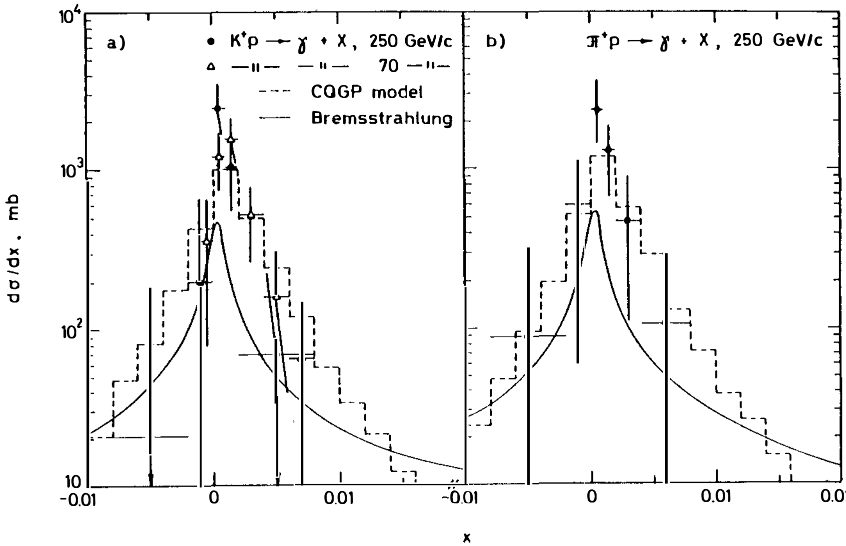


Fig.4 The $d\sigma/dx$ spectrum of γ's after subtraction of all hadron decays[23]. The curves show the hadronic bremsstrahlung contribution and the CQGP model prediction.

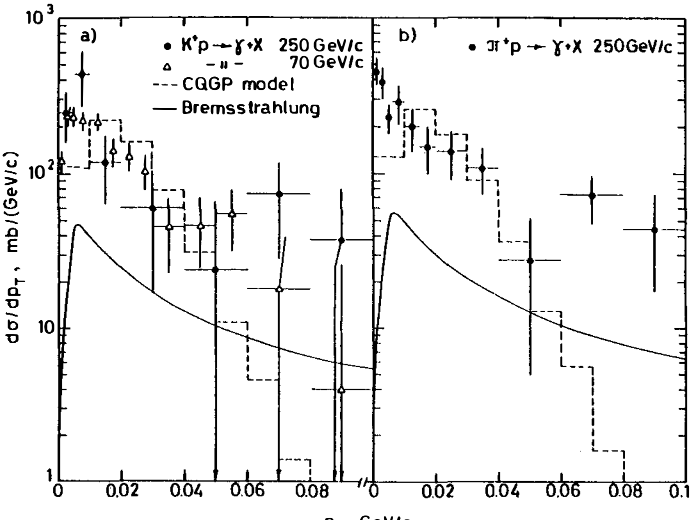


Fig.5 The $d\sigma/dp_T$ spectrum of γ's remaining after subtraction of all hadron decays[23]. The curves show the hadronic bremsstrahlung contribution and the CQGP model prediction.

3 Strangeness Production

Strange particles have many advantages for the study of particle production. They are in general more directly produced than pions, or at least carry more of the energy of the primarily produced meson. Strange particles can be used as a tag to allow the study of $q\bar{q}$ correlations on a much smaller combinatorial background than possible in $\pi\pi$ correlations. Strangeness can be used as a label to follow the fate of an incident valence quark through the collision to the final state particle. Λ^0 allows to study polarization in particle production. Finally, strange quark suppression $\lambda_s = s\bar{s}/\frac{1}{2}(u\bar{u} + d\bar{d})$ can give us information on the energy density, e.g. in the flux tube from the string tension κ in $\exp(-\pi m_q^2/\kappa)$.

In general, λ_s is assumed constant. Recent results, however, show that this is far from reality.

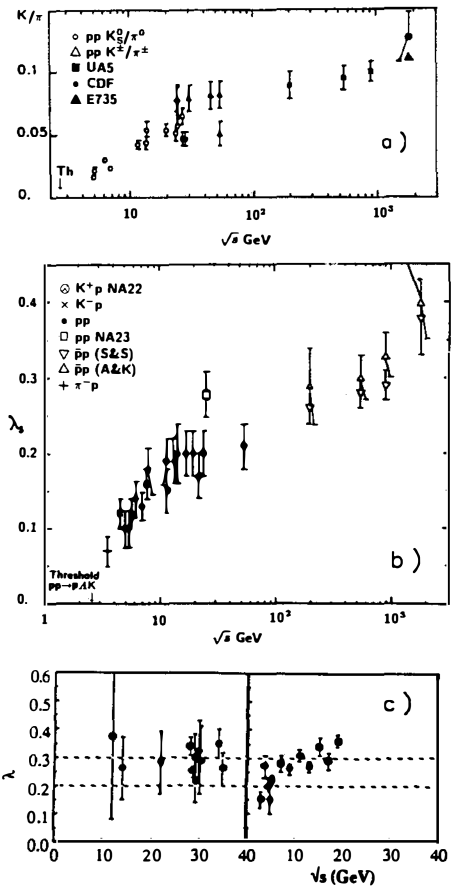


Fig.6 a) Energy dependence of the K/π ratio in $pp^{\pm}$ collisions[24,25,26], b) of the strangeness suppression λ_s in hp collisions[27], c) in e^+e^- and lh collisions[28].

3.1 *The energy dependence* between threshold and 1.8 TeV of the K/π ratio for minimum bias pp and $p\bar{p}$ events[24,25,26] is given in Fig.6a). Fig.6b) shows the strangeness suppression factor λ_s [27]. Both K/π and λ_s continue to rise through the CERN Collider and Tevatron energies. While λ_s first seemed to saturate at $\lambda_s = 0.2$ at ISR energies, it is now already above $\lambda_s = 0.35$ at 1.8 TeV.

It is interesting to note that similar values are reached in e^+e^- collisions already at much lower energies (Fig.6c [28]).

3.2 The *density (multiplicity) dependence* of the K/π and $\bar{p}/\pi^-$ ratio[26] is given in Fig.7a up to $n_{ch} = 120$ ($n_{ch}/d\eta \approx 20$). Over this multiplicity range, the K/π ratio grows by a much as 40%, On the other hand, the $\bar{p}/\pi^-$ ratio in Fig.7b) remains constant.

3.3 The p_t *and* m_t *dependence* of K/π and $\bar{p}/\pi^-$ ratios have recently been studied by UA2[29] and E735[26]. As can be seen from Fig.8a), both ratios increase as a function of p_t.

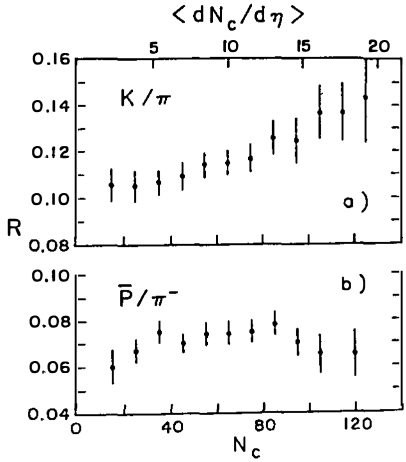


Fig.7 Ratios of a) K/π and b) $\bar{p}/\pi^-$ as a function of charge multiplicity N_c [26].

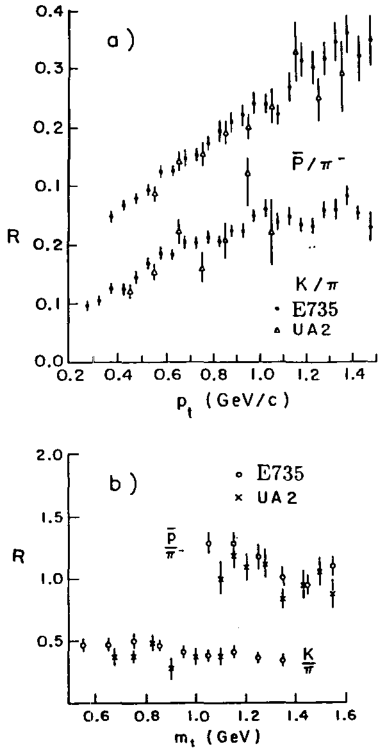


Fig.8 Ratios of K/π and $\bar{p}/\pi$ as a functions of a) p_t and b) m_t [28,29].

On the other hand, there is even an indication for a small decrease in m_t (Fig.8b).

3.4 The *Feynman x dependence* of strangeness suppression is less clear, but evidence exists also for that. K^* and ϕ have approximately the same mass and are produced more directly than K and π. In a K^+ beam, the $\bar{s}$ quark carries on the average more momentum than the u quark[30] and Monte Carlo Models show that K^* production from the u quark is strongly suppressed in the fragmentation region. After removing diffraction-dissociation and $K^*(1420)$ production, forward K^* therefore contains theoriginal $\bar{s}$ quark and a u-quark from the sea. A forward ϕ contains the original $\bar{s}$ quark and an $\bar{s}$-quark from the sea. Because of the similar mass and the direct production of these resonances, their production ratio can be used as a direct measure of λ_s.

In Fig.9a[31] the x dependence of K^{*0} and ϕ production is compared for K^+p experiments between 32 and 250 GeV/c. The ratios for the integrated forward region ($x \geq 0.2$) of $0.16 \pm 0.01 \pm 0.01$, $0.15 \pm 0.01 \pm 0.01$ and $0.17 \pm 0.01 \pm 0.01$ at 32, 70 and 250 GeV/c, respectively, are included in Fig.6b. The ratio of the ϕ and K^{*0} distribution at the three energies and the corresponding ratio from K^-p collisions at 110 GeV/c [32] are given in Fig.9b. Errors are large, but there is an indication for a decrease of this ratio (and therefore of λ_s) with increasing x. Confirming evidence comes from Λ [33] and K^0 [34] production in the same experiment, where $\lambda_s \geq 0.3$ appears necessary in the central, but $\lambda_s \leq 0.2$ in the proton fragmentation region.

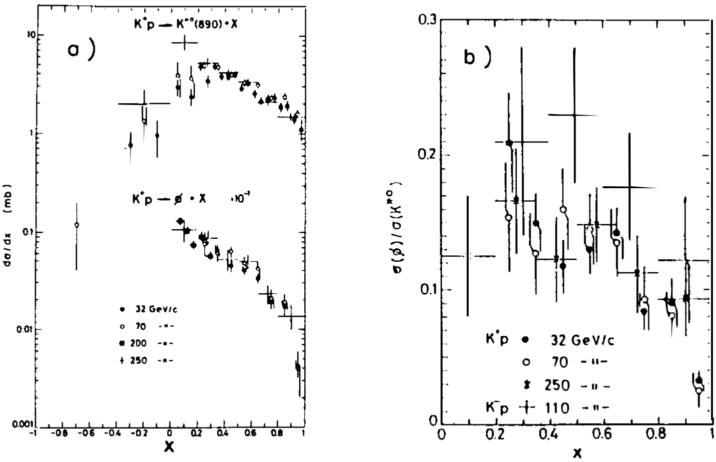


Fig.9 a) $d\sigma/dx$ of K^{*0} and ϕ in K^+p collisions[31], b) ratio of ϕ and K^{*0} distributions in K^+p and K^-p collisions [31,32].

An x dependence of s quark production is indeed expected in the quark-gluon string model of Kaĭdalov [35], from improved low Q^2 fragmentation functions. There, the ratios of fragmentation functions, however, lead to an *increase* of the K^+/π^+ ratio with increasing $|x|$, for directly produced K^+ and π^+. A full Monte Carlo now exists[36] and should be tested on the available data on energy, transverse momentum and Feynman x dependence of the K/π ratio and Λ production.

4 Conclusions

The correlators $\langle F_{ij}\rangle$ increase with decreasing correlation length D, but only approximately follow a power law for $D\lesssim 1$. For fixed D the values of $\langle F_{ij}\rangle$ are independent of the resolution δy, a feature expected from the α model, but also reproduced by FRITIOF and probably common to any model with short range order. The powers f_{ij} increase linearly with the product ij of the orders, but are considerably larger than expected from FRITIOF and from the simple α model. Agreement with the α model is restored with a 3 dimensional intermittency ansatz.

Besides earlier evidence for soft e^+e^- pair production, good evidence now exists for an "anomalous" direct soft signal with a cross section several times larger than that expected from inner hadronic QED bremsstrahlung. The data on direct photon emission at 70 and 250 GeV/c agree with the predictions of Lichard and Van Hove based on the existence of "globs" of cold quark-parton matter.

The K/π ratio, and with it the strangeness suppression factor λ_s, increases with increasing $\sqrt{s}$ up to Tevatron energies, where a value $\lambda_s \approx 0.35$ is reached. While the $\bar{p}/\pi$ is largely independent of the multiplcity n, the K/π ratio increases with increasing n. Both K/π and $\bar{p}/\pi$ increase with increasing transverse momentum p_t, but slightly decrease with increasing transverse mass m_t. A number of results at $\sqrt{s}$=22 GeV (p_{lab} = 250 GeV/c) point in the direction of a Feynman-x dependence of strangeness suppression, with $\lambda_s \gtrsim 0.3$ in the central and $\lambda_s \lesssim 0.2$ in the fragmentation regions.

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