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LOW MASS DILEPTON PRODUCTION IN HADRON COLLISIONS

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In the presented paper we compare the predictions of our model for the low mass dilepton continuum production in hadronic collisions with the KEK dielectron data. We also discuss the quark threshold effects and the general characteristics of hadrons produces in association with such low mass dileptons.

ОБРАЗОВАНИЕ ДИЛЕПТОНОВ МАЛОЙ МАССЫ В АДРОННЫХ СТОЛКНОВЕНИЯХ

В предлагаемой статье проводится сравнение предсказаний модели авторов для образования дилептонов малой массы в адронных столкновениях с КЭК-данными для диэлектронов. Обсуждаются также пороговые эффекты кварков и общие характеристики адронов, образованных совместно с дилептонами низкой массы.

I. INTRODUCTION

Direct lepton pair production has been one of the most discussed processes for already about ten years. The hunt for new particles as well as the possibility of application of perturbative QCD methods kept the interest of theorists and experimentalists mainly in the region of higher masses of dileptons. The situation there is now well understood within the framework of the Drell Yan model [1] corrected for the QCD effects together with the contributions from the J/ψ and the γ families.

The situation in the low mass region is still far from being settled [2]. Experimentally this region is complicated by the severe background due to many low-lying resonances. Theoretically, one can hardly go beyond the phenomenological level, since perturbative methods do not work here.

The first high statistics experiment in the low mass region was the one carried out

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by the Chicago—Princeton group [3]. They found a prominent continuum in the dimuon mass spectrum just above the threshold. This low mass dimuon continuum was reported by other groups as well [4].

The situation in e^+e^- low mass production is experimentally much less clear. Until recently there have been only two higher statistics experiments [5] which found no excess of dielectrons over the expected contribution from known sources such as the ω and the η Dalitz decays, but these experiments detected only dielectrons with relatively high transverse momenta. However, results from the new KEK experiment have appeared recently, covering the low mass and the low p_T region [6]. A clear continuum signal above the trivial sources was seen in this experiment in the low mass region.

It seems now that the presence of the low mass continuum is confirmed both in dimuon and dielectron experiments. Moreover, dimuons of a similar kind were observed in neutrino interactions as well [7]. Of course, because of the $\nu \to \mu$ weak transition these events are the trimuon ones. Thus, the low mass dilepton continuum is a common feature of all hadronic processes at high energies. An understanding of its origin may shed some light on the problem of hadron production in this energy region.

A few years ago some of us proposed a model for the production of this low mass (LM) continuum in hadron collisions [8]. The model was able to describe the early dimuon data [3]. In this paper we use the same model for the case of dielectron production and compare the results with the KEK preliminary data [6]. We found that the model is in a good shape. It represents well the basic features of both the dimuon and the dielectron production data and it has successfuly predicted [9] the existence and features of the trimuon events observed recently in the νN deep inelastic scattering [7].

However, there are several models on the market, and sometimes it is difficult to choose the one which one should prefer. In this context we shall briefly discuss the characteristics of hadrons produced in association with dilepton pairs. Data of this kind are not yet available, but are expected to appear in near future. Possibly, such data may help to resolve the question of the dynamical origin of the low mass dilepton continuum.

The paper is organized as follows: In the next section we briefly give some details about the model [8]. In Sec. III we compare the model calculation with the KEK data [6] and discuss the possible effects of the quark antiquark threshold. Sec. IV is devoted to the characteristics of the associated hadron production. The conclusions are contained in Sec. V.

II. THE MODEL OF THE LM CONTINUUM

Since our model for the production of the LM continuum in hadron collisions was described in details elsewhere [8, 10], we mention here just a few points of primary importance, in order to make the paper selfcontained.

The model is based on the Bjorken and Weisberg idea [11] that the LM continuum is due to the annihilations of those quarks (q's) and antiquarks ($\bar{q}$'s) which are created only during the high energy collision. This is contrary to the case of the Drell-Yan mechanism [1] which considers only quarks and antiquarks contained already in the incoming hadrons.

It was important to take into account the constraints imposed by the space-time evolution of high energy collisions as described by Bjorken [12] and Gribov [13]. During the relatively long time of the collision a complicated parton system is formed in the interaction region. However, in a given moment only a limited rapidity region of this parton system is excited. Thus only those q's and $\bar{q}$'s of this system can annihilate which are separated by small rapidity gaps. Such annihilations give rise to predominantly low-mass dileptons.

Referring for the details of kinematics to the original papers [8, 10] we present here only the final formula for the LM dilepton continuum production cross section in hadron collisions:

$$\sigma = \sigma_{inel} \int \sum_{Q} \mathrm{d}y_Q \, \mathrm{d}y_{\bar{Q}} \, \mathrm{d}^2\boldsymbol{P}_{TQ} \, \mathrm{d}^2\boldsymbol{P}_{T\bar{Q}} G(y_Q, \boldsymbol{P}_{TQ}, y_{\bar{Q}}, \boldsymbol{P}_{T\bar{Q}}) |\boldsymbol{V}_Q - \boldsymbol{V}_{\bar{Q}}| \times$$
$$\times \sigma_{Q\bar{Q}} \frac{1}{\cosh(y_Q)\cosh(y_{\bar{Q}})} \frac{\tau_0}{V_0} \exp[-A(y_{\bar{Q}} - y_Q)^2].$$

Here the $\sigma_{Q\bar{Q}}$ is the cross section for the $q\bar{q}$ annihilation into the dilepton, $G(y_Q\boldsymbol{P}_{TQ}y_{\bar{Q}}\boldsymbol{P}_{T\bar{Q}})$ is the joint probability distribution function to find a quark Q with the rapidity y_Q and the transverse momentum $\boldsymbol{p}_{TQ}$ and an antiquark $\bar{Q}$ with $y_{\bar{Q}}$ and $\boldsymbol{p}_{T\bar{Q}}$, in the parton system, which is formed during the collision. τ_0 and V_0 are the parameters of the model, giving the excitation time scale (τ_0) and the spatial volume (V_0) occupied by the wee partons. For the computations we used the values $\tau_0 = V_0^{1/3} = (0.21 \text{ GeV})^{-1}$ [8]. The functions $\cosh(y)$ are simple Lorentz factors, the function $\exp[-A(y_Q - y_{\bar{Q}})^2]$ describes phenomenologically the fact that only a limited rapidity region is simultaneously excited. All the calculations are done in a Monte Carlo way, since the distribution functions G are generated only implicitly by a Monte Carlo model of multiparticle production [14].

III. COMPARISON WITH DIELECTRON DATA

All the parameters of the model were fixed in the original paper [8] by comparison with the Chicago—Princeton data [3]. Now, good dielectron data became available, although at rather low energy ($\sqrt{s} = 5.12$ GeV) resulting from the Kaoto-KEK—Osaka City—Tokyo—Metropolitan—Savtava — INS [6] $p + Be$ experiment. We took the same values for our free parameters (specified in a previous study of LM $\mu^+\mu^-$ production [8]) and made a corresponding computer run in our model. The results are compared with the preliminary data [6] in Fig. 1.

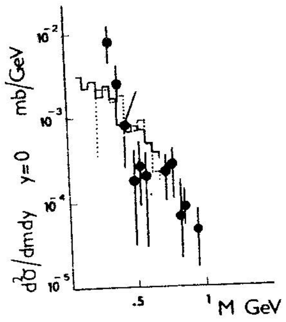

Fig. 1. Model calculations for the quark masses 0.01, 0.01 and 0.16 GeV — solid histogram, and 0.1, 0.1, 0.25 GeV — dotted histogram, compared with the preliminary data [6].

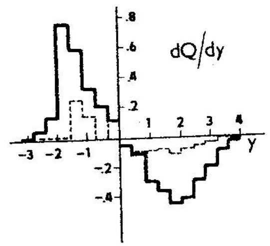

Fig. 2. Model calculations representing the charge rapidity distributions in normal multiparticle events — solid histograms, and in events with central Drell Yan lepton pair — dashed histogram, in πp collisions. Ref. [15].

Of course, to be precise, one should include the contribution from the ω and the η Dalitz decays and the $\varrho \rightarrow e^+e^-$ decays. This is not an easy task, because of lack of experimental information. However, even from the rough comparison presented in Fig. 1 one can see that at least the qualitative agreement is quite satisfactory. One should also keep in mind that the parameters of the model were fixed at a much higher energy. Although, on physical ground, one does not expect a strong dependence of these parameters on energy, a mild variation cannot be excluded.

We presented the results of two calculations corresponding to the two different sets of quark mass values: 0.01, 0.01, 0.15 GeV and 0.1, 0.1, 0.25 GeV for the u, d, and s quarks, respectively. Doing this, we wanted to illustrate the threshold effects of quark masses. If the quark masses are not extremely small, one should observe a threshold behaviour in the dielectron mass plot. Experimentally, the situation is not quite clear. However, the problem is a rather delicate one. Many complications are due to the Dalitz pair production and to some other mechanism like the virtual photon bremsstrahlung. Anyhow, good quality data in the very low mass region would be of primary interest.

IV. ASSOCIATED HADRON PRODUCTION

As we have already mentioned in the Introduction, the model is quite successful in describing various kinds of data of dilepton production at high energies. However, having in mind the existence of other models trying to describe the LM continuum production, it would be nice to test model predictions on data containing more information about the dilepton events. We have in mind data on the production of hadrons in association with dileptons. Here we shall discuss the expected characteristic of the associated hadron production to LM dileptons only qualitatively, by comparison with the same process in large dilepton masses which is believed to be due to the Drell Yan mechanism.

If the idea of the "hadronic-like" origin of the LM dileptons is correct one would expect the following two features to be found in the associative production data.

i) The spectrum of the leading hadrons produced in association with the LM dilepton with small rapidity is not significantly different from the spectrum observed in the events without dileptons.

ii) Rapidity spectra of directly produced hadrons in association with LM dilepton pairs are not influenced by the dilepton creation in the rapidity regions separated from the rapidity of the dilepton by approximately 1 to 2 units.

Both features are consequences of the fact that the creation of the LM dilepton is — in our model — local in rapidity.

The feature i) is in contrast to the situation which one should observe in the associated hadron production to dileptons of the Drell-Yan type. There, in the production of the central dileptons with a large mass the valence quarks of the incoming hadrons play a significant role. If the valence quark annihilates with an antiquark to a dilepton, it is no more active in the process of hadronization. This leads to the change of leading particle spectra with respect to the events without the lepton production. These differences are most easily seen in the rapidity distributions of the charge in the final state. The missing quark charge is recognized in Fig. 2, which represents calculations from Ref. [15]. In the spectra of hadrons associated with the LM dileptons one should not see any such effect.

The feature ii) is more difficult to be tested experimentally. It is essential to have spectra of directly produced hadrons, i.e. resonances, unless one is really at very high energies (even the ISR energy would be too small). This is due to the fact that resonance decays would smear the spectra and this would make difficulties in testing the predicted behaviour. However this feature would be really essential to be tested, since it is here that the locality of the LM pair creation is significant. Just for illustration we mention here the recent model by Goldman, Duong-van and Blankenbecler, where the situation is different [16]. Their model for the production of the LM continuum is based on the CIM idea that in addition to the quark antiquark collision in the Drell Yan process one should take into account also other possible effective constituents such as diquarks or mesons. In their model the production mechanism of the LM dileptons is not local in rapidity.

It seems that a really convincing explanation of the LM dilepton production is possible only if the models make at the same time detailed quantitative predictions for both the multiparticle and the LM dilepton production. Such an amibitions goal will still, however, require a lot of work and time.

V. CONCLUSIONS

In the present paper we have shown that the recent dielectron data [6] are in a reasonable agreement with the predictions from the model in [8]. More attention should be given to the region of the lowest dielectron masses, where quark mass threshold effects could possibly be seen.

Since various models seem to describe the dilepton data well, one should look for the application of the model to slightly different situations in order to check the validity of the model assumptions. We have argued that associated hadron production experiments can be of some help here. Data of this type are, unfortunately, not available to date.

However, one can hope to have such data in the near future. Hadrons produced in association with dielectrons are proposed to be studied [17] at the HYPERON experiment at JINR, Dubna. Here the dielectrons should be detected by the lead glass wall and the hadrons coming through the hole in the wall should be measured inclusively by the HYPERON spectrometer. A similar experiment with a different geometry of detector is proposed for the BIS-2 [18] spectrometer.

Hadrons produced in association with dimuons are proposed to be studied in the RISK streamer chamber [19]. Being triggered by the dimuon, the streamer chamber should provide an exclusive information on asociated hadrons.

Similar experiments would be surely done in other laboratories as well, since the interest of experimentalists pointed for a long time to the high mass dilepton region seems to approach the low mass end the dilepton spectra. One can only hope that good quality data on asociated hadron production to the LM continuum dileptons will soon be available.

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