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HADRONIC CONTRIBUTIONS TO TRIMUON PRODUCTION IN LEPTON-HADRON COLLISIONS

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We argue that the production of "additional" low mass muon pairs at relative level of 10^{-4} is a universal feature of the reactions in which hadronic jets are formed. Such dimuons arise from annihilations of quarks and antiquarks created during the space-time evolution of a jet. Contributions to the production of trimuons in lepton-hadron reactions are estimated.

Since the first observation of dimuon events in νN and $\bar{\nu}$N interactions [1] the statistics has increased considerably and now the data seem to support [2] the charm origin [3] of the "extra" muon. On the other hand, the poor statistics of events with an "extra" muon pair (trimuon events in μN or νN) does not allow to draw the definitive conclusions about their origin.

The situation is much better in hadron-hadron collisions, where the detailed experimental studies [4, 5, 6] of direct lepton pair production have discovered several important features:

— a substantial part of single leptons comes from lepton pairs,

— the production of dileptons with large masses [6] seems to be well described by the Drell-Yan mechanism [7],

— an important contribution to lepton pair production is provided by copiously produced low mass continuum, which is seen as an enhancement in $d\sigma/dM_{\mu\mu}$ below the ϱ-mass region.

We have recently proposed [8] a dynamical model for the origin of low mass dimuon continuum in hadron-hadron collisions which reproduces correctly the main features of the data [4]. In this note we first give the arguments showing that the mechanism of low mass dimuon production proposed in Ref. [8] operates also in lepton-hadron collisions.

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Then we present qualitative estimates of the production of such "extra" muon pairs in deep inelastic μN and νN interactions.

According to our model [8] low mass dimuons originate from the annihilations of quarks (Q) and antiquarks ($\overline{\text{Q}}$) created during the collision [9]. The total ammount of such Q's and $\overline{\text{Q}}$'s is fixed by the multiparticle production [10]. The annihilations $\text{Q}\overline{\text{Q}} \to \mu^+\mu^-$ are strongly influenced by the space-time evolution of the collision. According to Bjorken [11] and Gribov [12] the collision starts by the interaction of wee partons around $y \approx 0$ and this excitation gradually proceeds to larger values of y. The regions excited at $t \sim t_0\text{ch}(y)$ ($t_0 \sim 1$ fermi/c) are shown in Fig. 1. The dimension in rapidity of the excited region is $\Delta y \sim 1-2$. The parton systems separated by large rapidity gaps get excited at different moments. Because of that a Q and an $\overline{\text{Q}}$ created during the collision can annihilate only if $|y_{\text{Q}} - y_{\overline{\text{Q}}}|$ is smaller than Δy and consequently they can produce only dimuon with rather low mass.

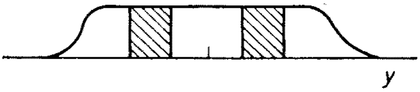

Fig. 1. The rapidity regions excited at time $t \sim t_0\,\text{ch}(y)$

This mechanism leads naturally to a close relationship between low mass dimuon and neutral meson productions. The former is due to the annihilation and the latter to the recombination [10] of a Q and an $\overline{\text{Q}}$ separated in both cases by a small rapidity gap.

Large mass dimuons are supposed to be produced by the Drell–Yan mechanism, which is a hard (i.e. long range in rapidity) process operating at the beginning of the collision (before the space-time evolution sets in).

Deep inelastic lepton-hadron interaction starts with the absorption of a virtual γ (in eN and μN) or W (in νN and $\bar{\nu}$N) collisions by one of the partons within the nucleon. This stage of the process is quite different from the case of the wee-parton interaction in hadron-hadron collisions. But the parton which has been kicked out of the nucleon cannot freely escape (due to confinement forces) from the interaction region. The large rapidity gap formed at the beginning of the process is subsequently filled by a "cloud" consisting of Q's and $\overline{\text{Q}}$'s. There are indications [11] that this process starts again from the origin of the corresponding c.m. system. Furthermore, the comparison of multiparticle production in lepton-hadron and hadron-hadron collisions [13] indicates that the main characteristics of excited parton systems are about the same in both cases. For example, the average hadron multiplicities seem to depend only on the total energy and not on the type of the process.

It is therefore plausible to assume that the space-time evolution of the excited parton system (and consequently also the mechanism of the production of both hadrons and dileptons) in lepton induced reactions is quite similar to that in hadron-hadron collisions [11, 14]. The same probably concerns all processes in which hadronic jets are formed (e^+e^- annihilation, large p_T processes).

In calculating the number of annihilations $\text{Q}\overline{\text{Q}} \to \mu^+\mu^-$ per inelastic event we could proceed, in principle, similarly as in Ref. [8], i.e. to generate exclusive configurations of Q's and $\bar{Q}$'s according to the procedure described in detail in Ref. [10], and then to include the $Q\bar{Q}$ annihilation cross section modified by factors which reflect our notion of the space-time evolution of the process.

In this note we, however, perform only simple and more transparent qualitative estimates.

From the calculations of dimuon production in hadronic collisions [8] we have learned that the average number of low mass (LM) dimuons per inelastic collision is given as

$$\langle \mu^+\mu^- \rangle_{\mathrm{LM}} \approx 0.3 \times 10^{-4} \langle \pi^+ \rangle. \tag{1}$$

The conjectured dynamical similarity of multiparticle production in hadron- and lepton--induced reactions indicates that the same estimate holds also in the latter case. The data [4] show that about the same number of dimuons comes from dimuon decays of vector mesons. In this way we get

$$\langle \mu^+\mu^- \rangle_{\mathrm{LM}} + \langle \mu^+\mu^- \rangle_{\varrho,\omega,\phi} \approx 0.6 \times 10^{-4} \langle \pi^+ \rangle. \tag{2}$$

In μN and νN collisions the "extra" dimuons should manifest themselves as trimuon events. Taking the average energy of the excited hadronic system in νN or μN interactions at present FNAL and SPS energies as $\langle W \rangle \approx 10$ GeV we have $\langle \pi^+ \rangle \approx 2.5$ and consequently

$$\frac{\sigma(\nu \mathrm{N} \to \mu\mu\mu X)}{\sigma(\nu \mathrm{N} \to \mu X)} \approx \frac{\sigma(\mu \mathrm{N} \to \mu\mu\mu X)}{\sigma(\mu \mathrm{N} \to \mu X)} \approx 1.5 \times 10^{-4}. \tag{3}$$

At present, there is experimental evidence for trimuons in νN [2, 15, 16] and μN [17] collisions. The estimated rate 5×10^{-4} [15] is about three times higher than that predicted by Eq. (3) what suggest that there are also other mechanisms of trimuon production. In fact, the data (six completely measured events) are consistent with leptonic origin of trimuons [18]. If, however, the model [8] is correct, and if the analogy between the dynamics of multiparticle production in hadron-hadron and lepton-hadron collisions is true, then the trimuons of hadronic origin will be found at the rate given roughly by Eq. (3) after the statistics is increased. They will manifest themselves by the low mass of the "extra" muon pair.

The same mechanism should work also in neutral current induced interactions in νN collisions. The rate of such events would be lower than that given by Eq. (3) by a factor N.C./C.C. and one could therefore expect

$$\frac{\sigma(\nu \mathrm{N} \to \mu\mu X)_{\mathrm{N.C.}}}{\sigma(\nu \mathrm{N} \to \mu X)} \approx 0.5 \times 10^{-4}.$$

This rate is rather low and dimuons of this origin are almost lost in charged current dimuon events in which the "extra" muon is of another (probably charm) origin. However, the neutral current induced dimuons can perhaps be disentangled from the rest thanks to two typical features of such events: (*i*) there is no leading muon, (*ii*) the mass of the muon pair is rather low ($\lesssim 1$ GeV/c^2).

In hadron-hadron collisions large mass dimuons are produced by the Drell–Yan mechanism, which takes into account the annihilations of Q's, which are present before the collision in one of the incoming hadrons, with $\overline{Q}$'s from the other, and vice versa. Such process is, of course, not possible in lepton-hadron interactions. But, perhaps a bit surprisingly, in lepton-hadron collisions one can imagine a similar process (referred to in what follows as the "internal Drell–Yan" — IDY — mechanism). A quark or an antiquark kicked out by the current from the nucleon tends to leave the interaction region.

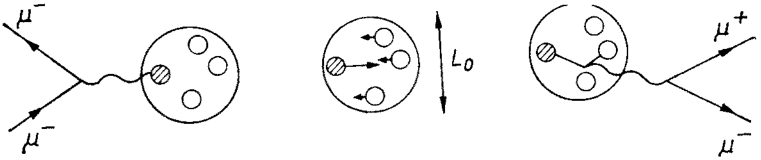

Fig. 2. A naive sketch of the "internal Drell-Yan process"

On its way out it moves through the rest of the nucleon and thus, before the evolution of a jet starts, it has a chance to annihilate with a corresponding partner to a dilepton. An order-of-magnitude estimate of the probability of such internal annihilation is given simply as (see Fig. 2)

$$P \approx \frac{\sigma_A}{L_0^2} N_{\overline{Q}},$$

where σ_A is the annihilation cross section, L_0 is the transverse dimension of the nucleon, and $N_{\overline{Q}}$ is the number of antiquarks present in the nucleon (we assume that the current was absorbed by a quark). Putting $\sigma_A \sim \alpha^2/M_{\mu\mu}^2$, $L_0 \sim 1/m_\pi$, $N_{\overline{Q}} \sim 1$ we obtain

$$P \approx \alpha^2 \left(\frac{m_\pi}{M_{\mu\mu}}\right)^2. \tag{4}$$

At small dimuon masses the rate corresponding to the IDY component (4) is lower than that of the LM component (2). But at large dimuon masses the LM component is negligible and the IDY takes over.

Now we shall leave the production of "extra" dimuons and discuss another process closely related to the IDY mechanism.

The IDY is a hard process occuring while the parton which has absorbed the virtual photon (or W-boson) moves within the nucleon. If this hard process is possible, than one can expect also the presence of other hard processes. In particular this concerns the elastic QQ or $Q\overline{Q}$ scattering leading to large p_T jets of hadrons [19–23]. Such jets have large p_T with respect to the direction of the virtual photon (or W-boson). The expected relative rate of these large p_T events is given as

$$P \approx \frac{\sigma_T}{L_0^2} N_Q, \tag{5}$$

where σ_T is the elastic QQ cross section, leading to the large p_T jet and $L_0 \sim 1/m_\pi$.

Taking the Field and Feynman [20] cross section for the hard QQ scattering

$$\left(\frac{d\sigma}{dt}\right)_{\mathrm{FF}} = 2.3\times 10^{6}\,\frac{1}{st^{3}}\left[\frac{\mu\mathrm{b}}{\mathrm{GeV}^{2}}\right] \tag{6}$$

then for $\sqrt{s} = 10$ GeV and $\sqrt{|t|} > 3$ GeV (considering only QQ collisions which lead to large p_{T} jets) we find

$$\sigma_{\mathrm{T}} \approx \int_{-\infty}^{-9} dt\left(\frac{d\sigma}{dt}\right)_{\mathrm{FF}} \approx 0.1\ \mathrm{mb}. \tag{7}$$

Inserting this into Eq. (5) we get a rough estimate of the relative rate of large p_{T} jets in νN collisions

$$\frac{\sigma(\nu\mathrm{N} \to \mu + \text{large } p_{\mathrm{T}} \text{ jets})}{\sigma(\nu\mathrm{N} \to \mu + X)} \approx 10^{-2}.$$

Such events can perhaps be seen in experiments capable of measuring directions of hadrons produced in deep inelastic νN and eN (or μN) collisions. A bubble chamber seems to be quite suitable for this purpose for νN interactions. Although being very difficult experimentally, the observation of such events would be a nice confirmation of parton model ideas.

The lepton-induced reactions, we have discussed in this note are all of a very small cross section. However, having in mind the recent tremendous increase of statistics of dimuon events [24] one can hope to have more detailed information about the processes with rates lower by two orders of magnitude in near future.

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REFERENCES

[1] A. Benvenuti et al., *Phys. Rev. Lett.* **34**, 419 (1975).

[2] F. Dydak, Talk at the Triangle Meeting, Raach near Vienna, May 1977, unpublished.

[3] B. W. Lee, *Dimuon Events*, preprint Fermilab–Conf–75/78–THY (unpublished); L. M. Sehgal, P. M. Zervas, *Phys. Rev. Lett.* **36**, 399 (1976) and *Nucl. Phys.* **B108**, 483 (1976); V. Černý, J. Pišút, Proc. of the Neutrino'75 Conf. ,Balatonfüred, June 1975, Vol II, p. 244, ed. A. Frenkel and G. Marx, and *Acta Phys. Slovaca* **27**, 28 (1977).

[4] K. J. Anderson et al., *Phys. Rev. Lett.* **37**, 799 (1976) and *Phys. Rev. Lett.* **37**, 803 (1976).

[5] H. Kasha et al., *Properties of Prompt Leptons*, presented at the XVIII Int. Conf. on High Energy Physics, Tbilisi, July 1976 (unpublished).

[6] D. C. Hom et al., *Phys. Rev. Lett.* **36**, 1236 (1976) and *Phys. Rev. Lett.* **37**, 1374 (1976); L. Kluberg et al., *Phys. Rev. Lett.* **37**, 1451 (1976).

[7] S. D. Drell, T. M. Yan, *Phys. Rev. Lett.* **25**, 316 (1970) and *Ann. Phys.* (N. Y.) **66**, 578 (1971).

[8] V. Černý, P. Lichard, J. Pišút, *Phys. Lett.* **70B**, 61 (1977); V. Černý, P. Lichard, J. Pišút, *Production of Dileptons During the Space-Time Evolution of Hadronic Collisions*, Bratislava preprint 1977.

[9] J. D Bjorken, H. Weisberg, *Phys. Rev.* **D13**, 1405 (1976).

[10] V. Černý, P. Lichard, J. Pišút, *Monte Carlo Approach to Multiparticle Production in a Quark-Parton Model*, to be published in *Phys. Rev.* D (1977).

[11] J. D. Bjorken, *Current Induced Reactions*, Lecture Notes in Physics, Vol. 56, Springer Verlag 1976, ed. J. G. Körner, G. Kramer and D. Schildknecht; Proc. of the Summer Inst. on Particle Physics, SLAC-Report-167 1973, ed. M. Zipf.

[12] V. N. Gribov, *Elementary Particles*, Vol. I., p. 65, First ITEP School on Theoretical Physics, Atomizdat, Moscow 1973.

[13] C. A. Heusch, *Inelastic Charged Lepton Scattering off Nucleons*, Rapp. talk at the Int. Conf. Neutrino'76, Aachen, preprint SLAC-PUB 1836, Nov. 1976.

[14] R. P. Feynman, *Photon-Hadron Interactions*, W. A. Benjamin, 1972.

[15] A. Benvenuti et al., *Phys. Rev. Lett.* **38**, 1110 (1977).

[16] B. C. Barisch et al. *Phys. Rev. Lett.* **38**, 577 (1977).

[17] K. W. Chen, *Dimuon and Trimuon Production in Deep Inelastic Muon Interactions at 150 GeV/c*, inv. talk at the int. conf. on new particles with new quantum numbers, Madison, April 1976, Michigan State Univ. preprint MSU–CSL–33, May 1976; C. Chang, K. W. Chen, A. van Ginneken, *Dimuon and Trimuon Final States in Deep Inelastic Muon Scattering*, preprint MSU–CSL–38, subm. to *Phys Rev. Lett.*

[18] C. Rubbia, Talk at the Triangle Meeting, Raach near Vienna, May 1977, unpublished.

[19] S. D. Ellis, M. Kislinger, *Phys. Rev.* **D9**, 2027 (1974).

[20] R. D. Field, R. P. Feynman, *Phys. Rev.* **D15**, 2590 (1977); R. D. Field, *Implications of Recent Large p_T Jet Trigger Data from Fermilab*, CALT–68–593; R. P. Feynman, *Correlations in Hadron Collisions at High Transverse Momentum*, Inv. talk at Orbis Scientiae 1977, Miami, Florida 1977, preprint CALT–68–588.

[21] V. Balek, V. Černý, J. Pišút, *Acta Phys. Slovaca* **27**, 81 (1977).

[22] W. Furmański, J. Wosiek, *Acta Phys. Pol.* **B8**, 633, 649 (1977).

[23] C. Bromberg et al., *Observation of the Production of Jets of Particles at High Transverse Momentum...*, preprint CALT–68–590.

[24] M. Holder et al., *Opposite Sign Dimuon Events Produced in Narrow Band Neutrino and Antineutrino Beams*, CERN preprint, May 1977, subm. to *Phys. Lett.*