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G. Parisi: e^+e^- ANNIHILATION INTO HADRONS IN THE PREASYMPTOTIC REGION AND $\mu^+\mu^-$ PRODUCTION IN PROTON COLLISIONS. -

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ABSTRACT. - Parton model predictions are compared with the ADONE data. The relevance of the parton antiparton threshold is stressed and a simple explanation is given for the structure recently observed in the production of high mass $\mu^+\mu^-$ pairs in proton collisions.

Recently several models have been proposed[1,2,3] to describe the interaction of high q^2 virtual photons with hadronic matter, and various asymptotic formulae have been derived. While from SLAC data[4] we know that $q^2 = -1\ \mathrm{GeV}^2$ is nearly asymptotic, it is not very clear where the asymptotic region begins in the time like direction.

In this letter we want to speculate on the possibility that, if q^2 is time like, the asymptotic formulae can be used only for high q^2 ($q^2 > 10.15\ \mathrm{GeV}^2$). We shall also make predictions on the behaviour of the cross section for e^+e^- annihilations into hadrons in the preasymptotic region. We shall also find support to our claims in the recent data on the production of high mass $\mu^+\mu^-$ pairs in the process $p+p \to \mu^+ + \mu^- +$ + anything[5].

The general scheme is based on the parton model.

The main results we shall use are derived in ref. (3). They are the following:

The total cross section for e^+e^- hadrons is

(1) $$\sigma_h = \left[\frac{1}{4} \sum{}_{i\,\mathrm{spin}\,0} Q_i^2 + \sum{}_{j\,\mathrm{spin}\,1/2} Q_j^2 \right] \sigma_\mu$$

where Q_i is the charge of the i-th parton, and σ_μ is the cross section for the process $e^+e^- \to \mu^+\mu^-$.

It is well known that charged spin 1/2 partons have to exist in order to allow for a non zero transverse cross section in electron proton deep inelastic scattering[(2)]. Let us now assume that the partons belongs to an SU_3 reppresentation. Then the simplest possibility, for integrally charged partons, is to assigne them to an octet. There will be four charged partons with the same charge quantum numbers as $P, \Sigma^+, \Sigma^-, \Xi^-$. We do not need to assume positive intrinsic parity.

The asymptotic cross section will be equal to 4, 4.5, 5 x σ_μ if there are respectively 0, 1, 2 meson octets and only one fermion octet.

In any case one must have in the asymptotic region:

(2) $$\sigma_h \geq 4\sigma_\mu \,.$$

As long as the proton form factor goes to zero when $q^2 \rightarrow -\infty$, we must identify partons with barionic resonances rather than with the nucleon octet. Their mass can be about 1.5 GeV.

The hadrons produced in e^+e^- annihilation cluster into Jets, having opposite charge quantum numbers.

The cross section for the production of two jets of masses m_1 and m_2, the first having the quantum numbers of the i-th parton, and the other the conjugated, is:

(3) $$\frac{d^2\sigma}{dm_1^2\, dm_2^2} = \rho_i(m_1^2)\, \rho_i(m_2^2) \quad {}_\mu \frac{(2J+1)^2}{4}$$

where $\rho_i(m^2)$ is the spectral function of the field associated to the i-th parton and J is the spin of the parton (possible values 0, 1/2).

Using the Lehmann sum rule, $\int \rho_i(m^2) dm^2 = 1$ one finds again formula (1).

This formulae are derived under the hypothesis $2E \gg m_1 + m_2$. If $2E \lesssim m_1 + m_2$ the jets formation, which is the main process for hadronic production in the asymptotic region, cannot occur; so there is not jets formation in this region.

If we are at such an energy that the low energy mechanisms (e.g. resonance production) are suppressed and high energy mechanisms are still not operative, the total cross section is sizeably less than its asymptotic value.

We can thus make the following predictions on hadron production in e^+e^- collisions. At a center-of-mass energy less than 3 GeV, the total cross section will be lower than the asymptotic one, the produced hadrons will show a nearly isotropic distribution, typical of resonance production or of the statistical model; if bosonic partons exist there will be a superimposed jet distribution as pointed out in ref. (3).

At a c.m. energy near 3 GeV the ratio of hadronic production with $\mu^+\mu^-$ production begins to grow quickly towards its asymptotic value. This rise is caused by an abundant production of pairs of barionic resonances; these resonances have of course the same quantum numbers as the partons.

We note that the first published results obtained at ADONE[6] indicate that the order of magnitude of σ_h at 2 GeV c.m. energy is 1 - 1.5 σ_μ. This value can be qualitatively understood in the present model. We are then led to predict that ratio σ_h/σ_μ shall show a typical threshold behaviour, it shall increase by a factor ~ 3 when the c.m. energy goes from 2.5 - 3 GeV to 4 - 5 GeV.

This peculiarity of the suggested behaviour in hadrons production in e^+e^- annihilation must have some consequences on the cross section for the production of high mass $\mu^+\mu^-$ pairs in pp collisions. Indeed we can say roughly speaking that, while in the first process we measure the number of hadronic states of fixed mass coupled to the electromagnetic current, in the second one we measure the probability that these states are produced in pp collisions and then they have an electromagnetic decay in $\mu^+\mu^-$.

So we are led to the conclusion that the cross section for the production of a $\mu^+\mu^-$ pair of fixed mass must show a structure about 3 GeV.

The experimental values[5] for $d\sigma/dm$ are plotted in Fig. 1.

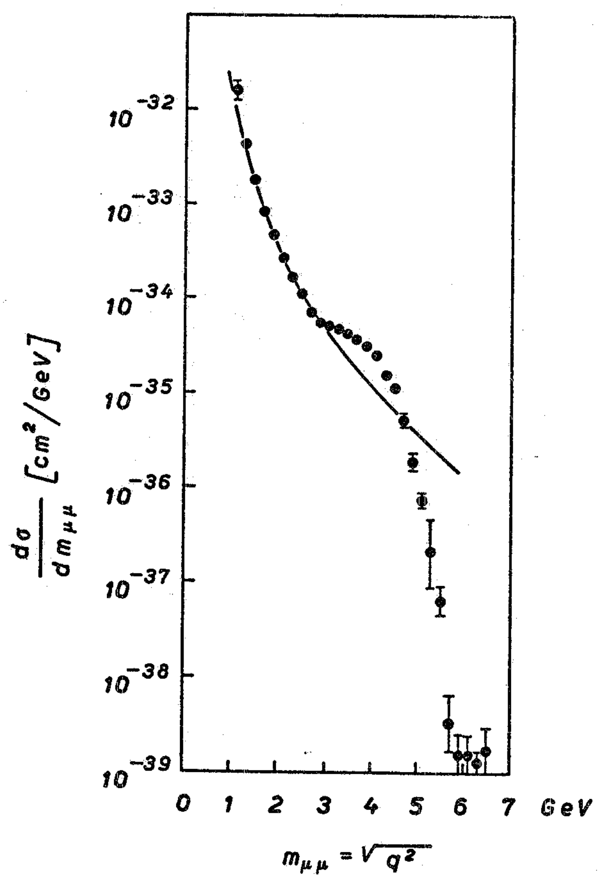

FIG. 1 - Differential cross section for the process $p + p \rightarrow \mu^+ + \mu^- +$ anything as given in ref. (5). The continuous line is a distribution of the form Cm^{-5}.

There is a marked shoulder at 3 GeV. The continuous line is a distribution of the form Cm^{-5}; this curve is a very good fit between 1 GeV and 3 GeV, but at 4 GeV is a factor 2 - 3 smaller than the experimental data. The rapid decrease after 4 GeV is a phase space effect.

We can thus conclude that in the framework of the parton model it is reasonable to assume that asymptotism begin at a relatively high value of timelike q^2. By this hypothesis we are able to give a simple physical explanation of the structure observed at 3 GeV in $\mu^+\mu^-$ production and to reconcile the parton model predictions with the cross sections measured at ADONE.

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