Search for light particles with a charge of 2/3 in e^+e^- annihilation

A. E. Bondar', L. M. Kuradze, M. Yu. Lel'chuk, V. S. Panin, V. A. Sidorov, A. G. Chilingarov, B. A. Shvarts, and S. I. Éĭdel'man
Institute of Nuclear Physics, Siberian Branch, Academy of Sciences of the USSR

(Submitted 5 October 1984)
Pis'ma Zh. Eksp. Teor. Fiz. **40**, No. 10, 440–442 (25 November 1984)

An upper limit has been found on the cross section for the production of particles with a charge of 2/3 and a mass up to 0.4 GeV in the reaction $e^+e^- \rightarrow q\bar{q}$ from measurements by the OLYa detector on the VÉPP-2M storage ring: $\sigma_{qq}/\sigma_{\mu\mu} < 10^{-4}$. This limit is two orders of magnitude lower than the results of previous experiments sensitive to quarks of small mass.

Experiments carried out with the OLYa detector on the VÉPP-2M storage ring used a luminosity integral of 1160 nb^{-1} over the energy range $W = 2E$ from 1.0 to 1.4 GeV (Refs. 1–3). These experimental results have been used to search for $e^+e^- \rightarrow q\bar{q}$ events, where q is a particle with a charge of 2/3.

The OLYa detector, described in detail in Ref. 2, consists of four identical quadrants around the beam-intersection region covering a total solid angle of $0.65 \cdot 4\pi$ sr. Each quadrant contains wire coordinate spark chambers, three scintillation counters, a shower detector, and a range system. For a detector to be triggered, there must be a simultaneous operation of all six scintillation counters of opposite quadrants. The total amount of matter in the path of a particle before it reaches the third counter is 9.5 g/cm^2. The threshold for the operation of each counter is set at $(0.20–0.25) \cdot A$, where A is the most probable amplitude for the particle of unit charge that would cause the least ionization.

In an analysis of the experimental data, we selected events containing in the coordinate chambers two tracks emerging from the region in which the e^+ and e^- beams interacted ($|\Delta x| < 70$ mm, $|\Delta y| < 10$ mm, $|\Delta z| < 10$ mm) with an angular deviation from collinearity less than 10°. A condition was imposed to suppress the background from many events: In the two quadrants lacking these tracks there could be no operation of the spark chambers or scintillation counters. On the basis of these criteria,

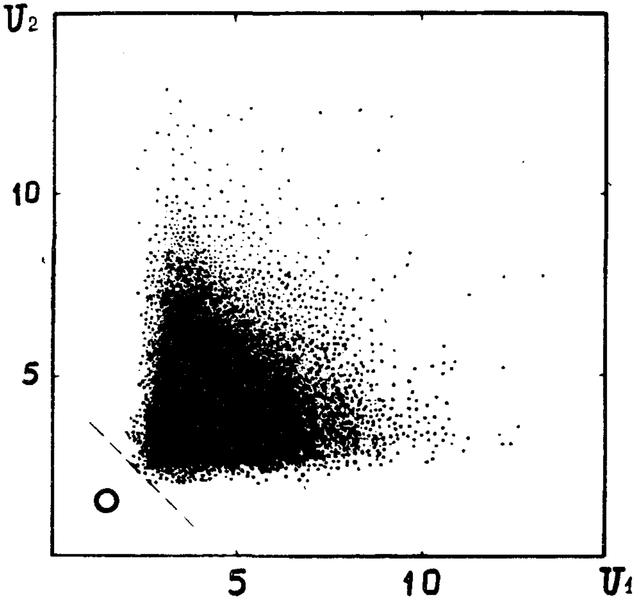

FIG. 1. Two-dimensional distribution of collinear events in the parameters U_1 and U_2. The dashed line is the limiting value of the sum $U_1 + U_2 = 4.78$, below which there are no events. The circle is the most probable position of $q\bar{q}$ events.

5×10^5 events were selected. Of these, 3×10^4 were identified as $e^+e^-\to\mu^+\mu^-$ events on the basis of the range of the particles in the range part of the detector.

The search for $e^+e^-\to q\bar{q}$ events was based on data on the ionization losses in the six scintillation counters. The amplitude of the signal from each counter was normalized to allow for the length of the path of the particle in the counter. The amplitude resolution of the counter (the width at half-maximum) was determined from $e^+e^-\to\mu^+\mu^-$ events to be 40%. For the collinear events selected, we calculated the sums of the amplitudes of the signals in the three counters of each quadrant with a track: U_1 and U_2. Figure 1 is a two-dimensional distribution in U_1 and U_2. The minimum value of the sum $U = U_1 + U_2$ found in these events is $U_{\min} = 4.78\cdot A$. For relativistic particles with a charge of 2/3, the average value of U should be $3.2\cdot A$. The absence of events with small amplitudes allows us to establish an upper limit on the cross section for the production of particles with a fractional charge, σ_{qq}.

The ratio $R = \sigma_{qq}/\sigma_{\mu\mu}$ depends on only the mass of the quarks if it is assumed that σ_{qq} depends on the energy in the same way as $\sigma_{\mu\mu}$ does. The number of $q\bar{q}$ events expected over the entire energy range would then be

$$N_{qq} = R\,(M)\,\sum_i \sigma_{\mu\mu}\,(W_i)\,L_i\,\epsilon\,(W_i, M, U_{\min}), \tag{1}$$

where L_i is the luminosity reached at the energy W_i, $\epsilon(W, M, U_{\min}) = BVD$ is the efficiency at which $q\bar{q}$ events are detected, M is the quark mass, B is the probability for particles to fall within the solid angle of the detector (the angular distribution of $q\bar{q}$ events was assumed to be the same as that for $\mu^+\mu^-$ events), V is the probability for a

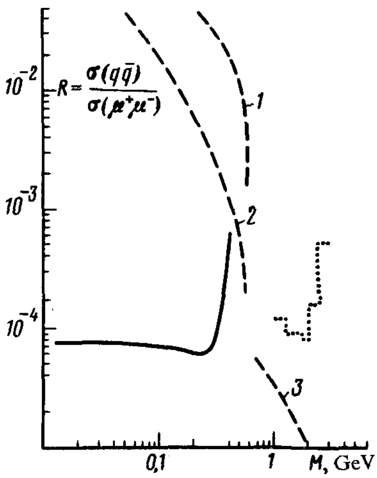

FIG. 2. Upper limit on R (at the 90% confidence level) versus the quark mass M. Solid curve—OLYa, VÉPP-2M; dotted line—MARK 2, SPEAR[4]; dashed curves—estimates of R in the model of Ref. 7; 1, 2—for the energy $W = 1.2$ GeV and for the parameter value $P = 1$ and 2, respectively, in the model; 3—for an energy $W = 5.2$ GeV corresponding to the experiment of Ref. 4, and $P = 1$.

pair of quarks to produce a sum of signal amplitudes in the counters less than $U_{\min}$, and D is the probability for the detection of the quark tracks in the coordinate system. The probabilities V and D were calculated on the basis of the characteristics of the counters and the chambers found with the help of $\mu^+\mu^-$ events.

An upper limit on $R(M)$ at the 90% confidence level (for $N_{qq} = 2.3$) has been found from expression (1): 10^{-4} for $M < 0.35$ GeV and 5×10^{-4} for $M = 0.4$ GeV. This upper limit is shown in Fig. 2, along with the limit imposed on R for quarks of large mass (1.0–2.8 GeV) by an experiment with the MARK 2 detector.[4] An upper limit $R < 10^{-2}$ had been found previously in experiments sensitive to quarks of small mass.[5,6]

Figure 2 also shows an estimate of R found from the model of Ref. 7 for the average energy of our experiment, 1.2 GeV, and for an energy of 5.2 GeV, corresponding to the experiment of Ref. 4. De Rujula *et al.*[7] have attempted to reconcile quantum chromodynamics with the existence of free quarks. This model predicts a rapid decrease in σ_{qq} with increasing energy W. The incorporation of such a $\sigma_{qq}(W)$ dependence in the analysis of the data leads to an expression more complicated than (1) but does not change the upper limit found from this experiment by a factor greater than two.

Quarks interacting strongly with matter were studied in Refs. 7–9. The limits on R given above do not allow for such an interaction. The thickness of the matter in the path of each particle in the OLYa detector was 0.14 nuclear collision length. If we assume that the cross section for the interaction with matter is the same for quarks as for hadrons, we conclude that the efficiency of the detection of $q\bar{q}$ events would have decreased by a factor of 1.3, so that the upper limit would be raised by a factor of 1.3. It can be seen from Fig. 2 that even with a much stronger interaction of the quarks with matter, the upper limit on R would remain below the prediction of the model of Ref. 7.

[1]L. M. Kurdadze et al., Yad. Fiz. **35**, 352 (1982) [Sov. J. Nucl. Phys. **35**, 201 (1982)].
[2]L. M. Kurdadze et al., Yad. Fiz. **40**, 451 (1984) [Sov. J. Nucl. Phys. **39**, No. 2 (1984)].
[3]P. M. Ivanov et al., Phys. Lett. **107B**, 297 (1981).
[4]J. M. Weiss et al., Phys. Lett. **101B**, 439 (1981).
[5]W. Bartel et al., Zh. Phys. **C6**, 295 (1980).
[6]W. Guryn et al., Phys. Lett. **139B**, 313 (1984).
[7]A. De Rujula et al., Phys. Rev. D **17**, 285 (1978).
[8]J. Orear, Phys. Rev. D **18**, 3504 (1978).
[9]D. Garelick, Phys. Rev. D **19**, 1026 (1979).

Translated by Dave Parsons
Edited by S. J. Amoretty