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LETTER OF INTENTION

To : Members of the Electronic Experiments Committee

From : J.V. Allaby, G. Bellettini, G. Cocconi, A.N. Diddens, G. Matthiae, E.J. Sacharidis, A.M. Wetherell

Re : A SEARCH FOR CHARGE $^1/_3$ PARTICLES AT THE CERN PS

It is proposed to pursue the search for charge $^1/_3$ particles ("quarks") at the CERN proton synchrotron, because it appears that the searches made thus far have not fully exploited the possibilities of existing accelerators. The method to be used consists in measuring ionization and time of flight of negative particles that have an apparent momentum, P_{app}, 20% higher than the momentum of the circulating beam in the accelerator. In a specially laid out beam, starting from target 1 at 0°, a quark production cross section of 10^{-39} cm^2/nucleon would result in about one event per week. In order to test the feasibility of the experiment, it is proposed to make a background measurement in the d beam in the South Hall.

1. Previous Results of Accelerator Experiments

The results of the two experiments that have given the lowest upper limits for the quark production cross section are collected in Table 1.

Table 1

(1) Ref.	(2) Proton Momentum (GeV/c)	(3) Target	(4) Prod. Angle (mr)	(5) P_{app} (GeV/c)	(6) Charge of quarks	(7) $\frac{d^2\sigma}{d\omega dP_{app}}$ (lab) $\left(\frac{cm^2}{sr.GeV/c.nucleon}\right)$	(8) σ_{tot} $\left(\frac{cm^2}{nucleon}\right)$
1	27.5	Cu	80	20	- 0.2 to -0.7	$\leq 1 \times 10^{-35}$	$\leq 10^{-35}$
2	30.0	Be	76	9	- 0.7 to -1.0	$\leq 3 \times 10^{-37}$	$\leq 10^{-37}$

Blum et al.[1] used an existing beam and employed a hydrogen bubble chamber in a search for particles with sub-normal ionization. Dorfan et al.[2] looked for stable particles heavier than 2 GeV. Their system was sensitive to particles of charge one, had a reduced sensitivity for charge $^2/_3$ and was not sensitive at all to charge $^1/_3$; the mass of the particles was deduced from measurements of velocity (Cerenkov counters and time of flight) and of momentum. In this last experiment the antideuteron was found.

The values given in column (7) of Table 1 are the results for the upper limits of the differential cross section. The figures quoted in column (8) of the table for the total cross sections have been obtained by the Authors assuming the production reaction

$$p + p \rightarrow p + p + Q + \overline{Q}$$

assigning to the quarks, Q, a mass near to the upper limit that can be reached at the PS or AGS ($\approx$ 2.5 GeV[7]) and assuming an isotropic c.m. angular distribution. Cross sections for still heavier quarks were also quoted, taking into account the tail of the Fermi distribution of the nucleons in the target.

2. Aim of the Proposal

The aim of the present proposal is a search for long lived negative quarks of charge $^1/_3$ (and hopefully also $^2/_3$) down to a production cross section of $\leq 10^{-39}$ cm^2/nucleon. The case of heavy particles of charge one will not be considered, as the Columbia experiment[2]) has already reached a rather low upper limit for that cross section.

Whether a detection threshold of 10^{-39} cm^2 is small enough to find quarks is debatable. Mention should be made, however, of a calculation by Maksimenko et al.[3]), along the lines of the statistical model that predicted a cross section for quark production depending exponentially on the mass of the quark, m_Q ,

$$\sigma_{tot} \propto e^{-2 m_Q/\mu}$$

where μ is the mass of the pion. Assuming strong coupling of the quarks to the nucleons and pions, they calculated $\sigma_{tot} = 10^{-37}$ cm^2 for $m_Q = 3$ GeV, a value appreciably smaller than the upper limit quoted in ref. 1. There is also the possibility, as pointed out by Freund et al.[4]) and Schiff[5]) that the quarks have a rather small mass, but that their production is reduced considerably by strong selection rules.

This being the situation and in view of the importance of establishing the existence of quarks, it seems worth while to search for them at a level of cross section which is appreciably below that established by the experiments so far.

3. Method and Counting Rate

The principle of the experiment is the same as that outlined in a previous proposal[6]) by this group. The experiment then proposed was never performed since at that time it was felt to be more profitable to use a bubble chamber as detector. Hence the experiment of Ref. 1 was performed.

Our method takes advantage of the following facts:

a) the particles sought have an apparent momentum, P_{app}, bigger than the momentum of the primary protons. This is due to the fact that in a bending magnet, particles of charge $^1/_3$ have an apparent momentum three times larger than their real momentum. Consequently the background in the experiment proposed is expected to be very small.

b) The ionizing power of the particles is $^1/_9$ times minimum, giving a very clear signature for their identification.

c) If the quarks are substantially heavier than nucleons, their time of flight over a 40 m base line is some nanoseconds longer than that of the known particles.

The production kinematics is shown in Fig. 1, which has been reproduced from ref. 6.

It is our intention to analyse a beam of negative secondary particles, produced at 0° in target 1, with apparent momentum 20% higher than the momentum of the circulating proton beam. The acceptance of the beam will be $\Delta\omega \approx 10^{-4}$ sr, $\Delta p/p \approx 10\%$. Along the beam we will measure the ionization, momentum, and time of flight several times with a counter system.

Assuming that the PS works for $4^1/_2$ days/week, 20 hours/day, at a repetition rate of $(2.3 \text{ sec})^{-1}$, and accelerates 9×10^{11} protons/burst, the number of protons accelerated per week is 1.25×10^{17}. If 20% of the circulating protons interact in target 1, (the remaining going to other targets or being lost) then 2.5×10^{16} protons interact in target 1 per week ($\equiv I_0$).

The number of quark events observed per week, N_w, is

$$N_w = \frac{d^2\sigma}{d\omega dP_{app}} \Delta\omega \Delta P_{app} \frac{I_0}{\sigma_T} .$$

Thus 10^{-38} cm^2/sr.GeV/c would produce 2.5 events/week.

A differential cross section of 10^{-38} cm^2/sr.GeV/c corresponds to a total cross section of about 2×10^{-39} cm^2, assuming that the usual transverse momentum dependence of secondaries holds and collimates the quarks to within a solid angle of 10^{-2} sr. For heavy quarks the total momentum range might be 20 GeV/c according to Fig. 1.

The beam for this experiment would require the floor space and the magnetic elements of the d beam in the South Hall. The proposed 0^0 production angle would, however, need the construction of some special features:

i) A window in the vacuum chamber inside magnet unit 1 of the PS.

ii) Two DC septum magnets to transport the beam from the PS into the d beam region. Minor modifications to the h_3 beam might be needed but this beam would remain operational.

From discussions with G. Petrucci this beam layout appears feasible. There are also alternative solutions possible.

The construction time for the special elements would be half a year or longer. The experiment would occupy the South Hall d beam region for a time long enough to permit a few months of data taking. In this time one could establish the existence of free quarks even if their production cross section is as small as 10^{-39} cm^2.

4. Proposal for a background study

Before embarking on such a programme, the following important question has to be settled: Is it possible to reduce the background to a level of a few events per week?

In order to resolve this question, we would like to request 2 weeks of running time in the d beam in the South Hall before Christmas 1966. During this test, the d beam will be used at its normal production angle, but tuned to particles of momentum 20% higher than the circulating protons in the PS.

REFERENCES

1. Blum, Brandt, Cocconi, Czyzewski, Danysz, Jobes, Kellner, Miller, Morrison, Neale, Rushbrooke, Phys.Rev.Letters 13, 353 (1964).
2. Dorfan, Eades, Lederman, Lee, Ting, Phys.Rev.Letters 14, 999 (1965).
3. Maksimenko, Sisakyan, Feinberg, Chernavskii, JETP Letters 3, 219 (1966).
4. Freund and Predazzi, Preprint University of Chicago, CUO 264-323, May 1966.
5. Schiff, Preprint Stanford University, ITP-231, Aug. 1966.
6. Cocconi, Diddens, Lillethun, Pahl, Scanlon, Walters, Wetherell, Proposal to EEC, 3.2.1964.
7. The maximum mass that can be produced on a stationary target in the production reaction is :

at P_0 = 20 GeV/c	$m_{Q_{max}} = m_{\bar{Q},max}$	= 2.20 GeV
P_0 = 25 GeV/c	" "	= 2.55 GeV
P_0 = 30 GeV/c	" "	= 2.87 GeV.

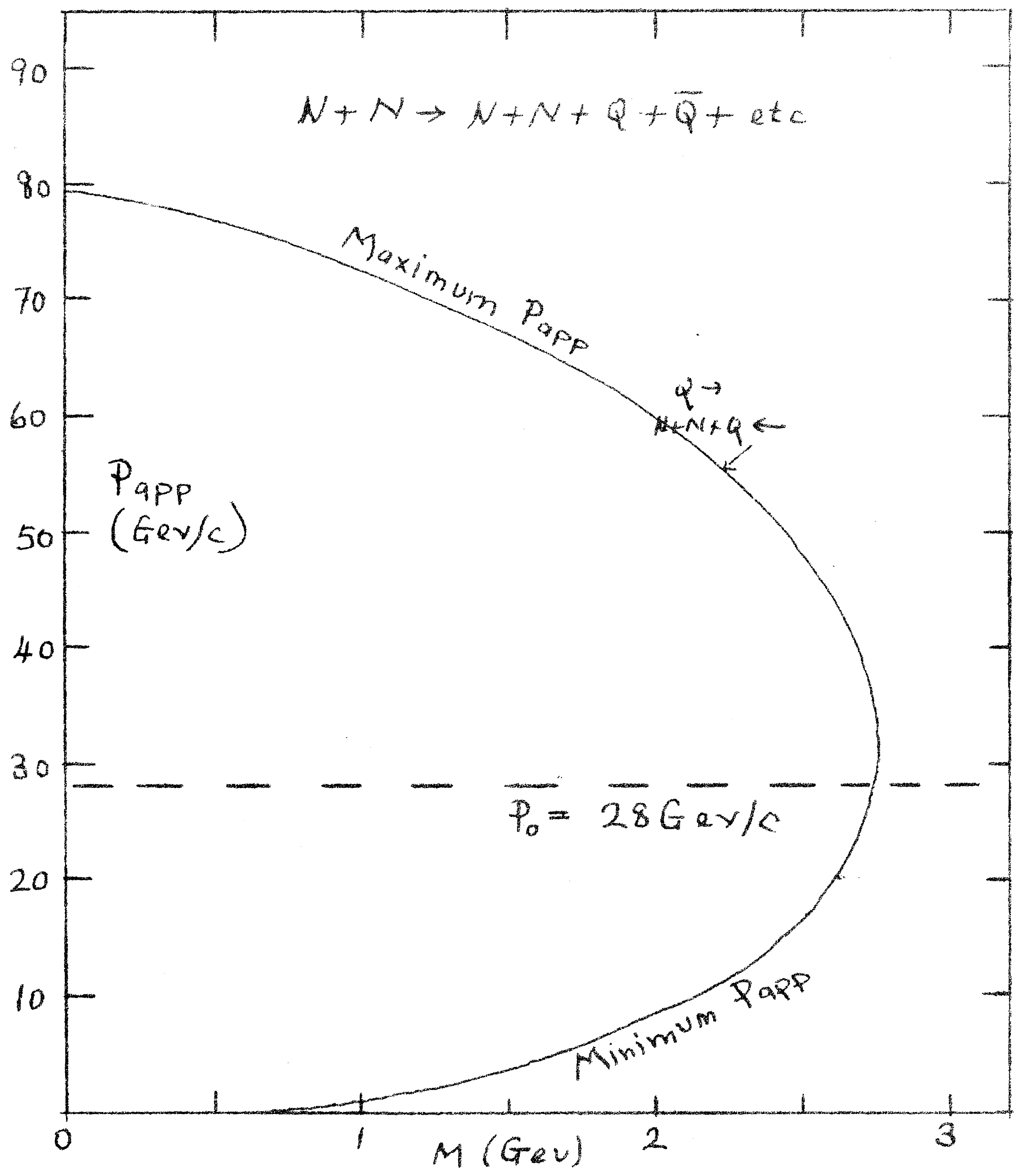

Figure 1: Maximum and minimum apparent momentum of quarks produced by 28 Gev/c protons, as a function of the quark mass, M.