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M E M O R A N D U M

To : Members of the ISR Committee  
From : M.G. Albrow, A.B. Clegg and J.C. Sens  
(CERN/Holland/Lancaster/Manchester Collaboration)  
Re : Search for Quarks at the ISR

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An experiment is presently in preparation by the CERN/Holland/Lancaster/Manchester collaboration with the purpose of measuring the production of stable particles in the angular interval  $\sim 20$ - $150$  mrad and momentum interval  $\sim 0$ - $28$  GeV/c at a range of c.m. energies between  $\sim 20$  and  $\sim 56$  GeV at the ISR. In this note we discuss the capability of the apparatus of this experiment to detect, in addition to the known particles, quarks and other massive particles, if they turn out to exist. The limits on the cross section are compared with those obtainable from an experiment, preliminarily proposed by D.O. Caldwell et al, which has been designed specifically for the detection of massive particles between  $\sim 5$  and  $25$  GeV mass.

The apparatus of the small angle production experiment consists of 5 magnets, placed in the vertical plane, wire chambers, time of flight,  $dE/dX$  and Čerenkov counters with which momentum, production angle, mass and charge of the particles produced can be obtained. The first two magnets are septum magnets. The minimum detectable angle is  $\sim 20$  mrad. The solid angle of the complete spectrometer is  $\sim 10^{-4}$  sr. The accepted momentum bite  $\pm 10\%$ . These numbers are too low to expect any meaningful upper limits on the cross section for very rare particles to be obtained.

This situation can be improved by separately triggering on events which pass through the two septum magnets, without requiring the remaining magnets to be traversed as well. From the dimensions and positions of the septa, set for a nominal momentum  $p_0$  and for minimum angle = 20 mrad we obtain the following limits on the accepted angles at the specified momenta.

Particle Momentum $p$	Angular Range Accepted (mrad)	
	$\theta_{\max}$	$\theta_{\min}$
0.69 $p_0$	20	20
1.0 $p_0$	20	33.5
1.2 $p_0$	24	38
1.5 $p_0$	26	40
2.0 $p_0$	27.5	41
$\infty$ $p_0$	37	43

For example with the septa set at  $p_0 = 4.5$  GeV/c (for integrally charged particles) the range of accepted momenta would be:

charge  $e$  3-25 GeV/c  
 charge  $\frac{2}{3}e$  2-25 GeV/c  
 charge  $\frac{1}{3}e$  1-25 GeV/c .

The mass/charge ratio  $M/q$  ( $M$  is the mass,  $q$  is the charge in units of  $e$ ) can be obtained from measurements of the radius of curvature in the fields and time of flight. Assuming a spark reconstruction error of  $\pm 0.5$  mm and a time of flight error of  $\pm 1$  nsec it is found that for all momenta

$$\frac{\delta (M/q)}{(M/q)} \leq \pm 20 \%$$

The rate of quark events through the two septum magnets is strongly dependent on the mechanism and the  $t$ -dependence in the production. To provide useful estimates we have assumed that the quark pair is produced with a cross section  $\sim A e^{bt}$ , and that the quark pair will take about half the total available energy (as would be consistent with a  $pp \rightarrow ppq\bar{q}$  mechanism). Each quark then has an average momentum of 7.5 GeV/c for 10 GeV mass. For an average  $\Theta_{\min} = 24$  mrad (see table) we then have  $t_{\min} = 0.11 \text{ GeV}^2$ , for  $\Theta_{\max} = 38$  mrad  $t_{\max} = 0.27 \text{ GeV}^2$ . The azimuthal acceptance of the septa is  $\Delta\phi = 20^\circ$ . For the distribution  $A e^{bt}$  we then obtain for the upper limit on the cross section, on the basis of one detected event per day:

$b$ GeV <sup>-2</sup>	$\sigma_{\text{limit}}$ cm <sup>2</sup>
3	$1.6 \times 10^{-34}$
8	$1.7 \times 10^{-34}$
15	$2.9 \times 10^{-34}$

Present limits (from cosmic rays) for the production of 10 GeV quarks are of the order of  $10^{-32} \text{ cm}^2$ , i.e. 30 to 60 times higher than the small angle particle production experiment can provide. For masses below 5 GeV, accelerators experiments have resulted in limits in the range  $10^{-34} - 10^{-39} \text{ cm}^2$  and hence no useful contribution can be made for this mass range.

Recently Caldwell et al<sup>1)</sup> have put forward a preliminary proposal to search for massive particles by means of counter hodoscopes and absorbers in which range,  $dE/dX$  and time of flight of slow particles ( $0.1 < \beta < 0.8$ ) are measured. The solid angle is 1.68 sr. For  $t_{\min} = 0$  and  $\Delta\phi = 2\pi$  the limit on the cross section with two hodoscopes is  $3 \times 10^{-36} \text{ cm}^2$  on the basis of one event per day.

This limit is certainly optimistic as it assumes that small angles can be reached at all azimuths. In practice, at the front end of the hodoscope,  $\Theta_{\min} \approx 20$  mrad can be reached above and below the

beam pipe but not on the sides. We have therefore calculated limiting cross sections assuming the same angular distribution as previously,  $\theta_{\min} = 20$  mrad, and an azimuthal acceptance of  $\frac{1}{2} \times 2\pi$  (which then also allows for dead space taken up by light guides, etc):

$b$ GeV <sup>-2</sup>	$\sigma$ limit (Caldwell et al.) cm <sup>2</sup>
3	$.8 \times 10^{-35}$
8	$1.4 \times 10^{-35}$
15	$3.0 \times 10^{-35}$

Hence, the apparatus of Caldwell et al can reach limits which are roughly 10 to 20 times lower than can be reached with the small angle particle production equipment. Note that the solid angle in Caldwell et al is  $\sim 1.6 \times 10^4$  times as large.

Another difference between the two experiments is that in the small angle spectrometer the momentum and hence the particle mass is accurately determined while in Caldwell et al in most cases only an upper limit on the mass can be obtained, due to (largely unknown) nuclear interactions in the range telescopes. A further difference is that of the total rate of events (protons, pions, etc) passing through the equipment. In Caldwell et al a quark is to be recognized in a total of  $\sim 2 \times 10^{10}$  events (protons, pions, etc) per day, in the small angle set-up there are  $\sim 5 \times 10^8$  such events per day.