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A Quark Search at the CBA

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I Quark Production at the CBA

If the quark containment mechanism admits of small leaks, free quarks might be observed under certain conditions. Moreover, it is plausible that the leakage, if there is any leakage, will be very strongly energy dependent. In particular, we might expect that such leakage might be observed in measurements of quark-antiquark pairs produced with very large invariant masses. Such pairs, in general contained, will be produced at the CBA with large cross sections which may be estimated intelligently. Knowing the production cross sections for massive quark pairs, measurements of the flux of free quarks defines a leakage ratio.

To estimate the cross sections for the production of massive quark-antiquark pairs in nucleon-nucleon collisions, we first discuss the cross section for the production of quark-antiquark pairs through virtual photons produced in the nucleon-nucleon collisions. This Drell-Yan flux has been determined through measurements of the flux of muon-pairs and Pope and Lederman have parameterized the muon pair production in a formula which scales. Multiplying the Pope-Lederman relation by R, where R is the usual ratio of hadron to lepton production in the parton model and is equal to 10/3 for three colors and the four light quark flavors, the electromagnetic production cross section of quark pairs with invariant masses greater than M by nucleon-nucleon collisions with values of the square of the center-of-mass energy of s, is written as,

$$\sigma \approx 3.3 \cdot E^{-36} \; R \, \frac{F(M^2/s)}{M^2} \; cm^2 \quad \text{where } F(x) = \frac{1-x}{(0.02+x)^3}$$

If we assume that intermediate gluons will act in a manner similar to that for intermediate photons, we might expect a contribution from the strong interactions of the order of $(\alpha_s/\alpha)^2 \approx 10^3$ times the electromagnetic contribution, where α_s is the nominal quark-gluon coupling constant. Noting, that typically strong interaction cross sections are better estimated as perhaps $\pi \cdot \alpha$ times electromagnetic cross sections, we use a very conservative figure of 100 for the ratio of strong interactions to the Drell-Yan contribution.

Values of the Drell-Yan cross section, our estimate of the strong interaction cross section, and the production rates in quark-pairs per second from a CBA with a luminosity of 10^{33} per second, are given in Table I.

	Drell-Yan		Strong Interactions		
M(GeV)	*σ*	*Flux*	*σ*	*Flux*	*Leakage*
30	$1.2\cdot10^{-33}$	1.2	$1.2\cdot E^{-31}$	120	$1.15\ E^{-7}$
50	$3.2\cdot10^{-34}$	0.32	$3.2\cdot E^{-32}$	32	$4.35\ E^{-7}$
100	$2.4\cdot10^{-35}$	0.024	$2.4\cdot E^{-33}$	2.4	$5.8\ 10^{-6}$
200	$5.0\cdot10^{-37}$	0.0005	$5.0\cdot E^{-35}$	0.05	$2.8\ E^{-4}$

Table I Cross sections and fluxes for the production of massive quark-antiquark pairs in 400 GeVX400GeV nucleon-nucleon collisions. The fluxes are measured in pairs per second.

Of course, in conventional views of containment, these quark pairs are manifest as hadron jets with no production of free quarks. Now with these numbers (or refined versions of these numbers) together with experimental results, one can determine the proportion (or a limit on that proportion) of the produced pairs which results in the "leakage" of free quarks. For example, a run of 1000 hours with a detection efficiency Of 10% for free quarks will give leakage limits shown in the last column of Table I assuming that 5 observed events constitutes a believable signal.

II Experimental Design and Procedures

With a luminosity of 10^{33}, there will be about $3\cdot10^{7}$ interactions per second in the interaction region. The charged particle multiplicity will be of the order of 20, the total hadron multiplicity will be about 30 particles per interaction giving a total hadron production of the order of 10^9 particles per second. Since we are searching for quark pairs with large invariant masses, produced in their own center-of-mass system with an angular distribution described adequately by the relation $d\sigma/d\Omega \approx 1-\cos^2\theta$ where θ is the angle between the quark emission direction and the beam direction, such quarks will often be produced at large angles.

Our detector, to be described, will cover about 2π sr from $\cos\theta = 0.5$ to $\cos\theta = -0.5$. Since we expect that the quark production will not be restricted nearly so strongly to small transverse momenta as hadron production in general, we estimate that the detector, centered at 90°, will accept about 20% of the quarks produced but less than 3% of other hadrons. Hence, in this angular interval, the hadron flux should not be large. [We note that the scaling of the inclusive invariant cross section $E\, d^3\sigma/dp^3$ tells us that there will be no more particles produced in this angular interval at CBA energies than at lower energies.] Indeed, we estimate that less than one charged particle per interaction will pass through the counters giving a total rate of about 10^7 particles per second.

We survive the high flux rates by segmentation of the detector: our detector is to be made up of 24 essentially independent elements where the rate in each will be only about $4\cdot10^5$ per second. In 1000 hours, a total of about $3.5\cdot10^{13}$ particles will pass through the whole detector -- or about $1.5 \cdot 10^{12}$ particles through each segment. Hence, if one quark is to be detected, the discrimination must be of the order of one in 10^{14}. In previous experiments we have demonstrated a discrimination of one in 10^{11} -- without reaching a discrimination limit. Since the background pulses in each counter which simulate the small energy loss of a quark are not correlated in energy and largely uncorrelated in time, the discrimination index is a nearly exponential function of the number and energy resolution of detector units and the design presented here, an extrapolation of previous designs, is meant to achieve a discrimination of 10^{14}.

The diagram of Fig. 1a presents a schematic view of the basic assembly of the detector. The fundamental concept is similar to that which our group has used in a program of quark searches which has been conducted over the past 20 years. The quarks are to be identified by their characteristically small energy loss in passing through the 8 scintillation counters which make up each of the 24 scintillation counter sections; a charge e/3 quark (p/mc > 1.5) will lose 1/9 as much energy as a minimum singly charged particle and a charge 2/3 particle will lose 4/9 as much energy. The cross sectional dimensions of the scintillator will be 6" by 1/2" and we expect to receive 15 photoelectrons initiated by the passage of an e/3 quark -- and 60 for a 2e/3 quark.

It is important to achieve high resolution in the pulse height determination inasmuch as the discrimination against backgrounds depends strongly on that resolution. Real events deposit very much the same energy in each scintillator, while the most serious backgrounds result from the chance juxtaposition in time and energy loss of small uncorrelated energy losses in each of the eight counters from soft photon or slow neutron backgrounds.

Since real quarks are to be differentiated from backgrounds by the equality of the normalized pulses in each counter, it is important to establish the criteria for equality in a satisfactory manner. Too loose a criteria will admit excessive backgrounds, too selective a measure may throw out real events. We set the criteria by generating "fake" quark events regularly by measuring artificially produced "quarks" generated by charge one particles passing through the scintillators where masks in front of the phototubes pass 1/9 or 4/9 of the scintillator light. Such a simulation is nearly exact, fitting the Landau dispersion as well as the mean pulse height. The masks are to be put in at intervals throughout the experiment and the relevant parameters will be adjusted so as to accept the (pseudo) quarks with high efficiency and discrimination against backgrounds.

The experiment will select events of interest through a hierarchy of acceptance criteria. Initially, events will be selected such that each of the eight element of any one sector generates a pulse greater than 0.03 times minimum and less than 0.7 times minimum. This selection would be made through standard discriminator logic in no more than 10 nsec. Each such trigger, would initiate 6 bit flash A to D converters acting on each element of that sector (and, perhaps, other sectors) to record the pulse heights with a resolution of about 0.015 times minimum. Such circuits act in about 25 nanoseconds. This information (i.e. 8 six-bit numbers) will be transferred to an on-line computer for further processing. However, if that rate is too high, preprocessing in hard-wired logic can be accomplished within the framework of a FASTBUS data handling system. At the on-line computer level, more sophisticated algorithms will then select as quark candidates only those events such that the normalized energy losses in each element of the triggered sector are about equal. Although, the raw data concerning each event transferred to the computer will be stored on magnetic tape, the experiment is envisioned as, essentially, an on-line experiment. With final results available immediately, subtle as well as egregious errors may be corrected in a timely manner as the experiment proceeds.

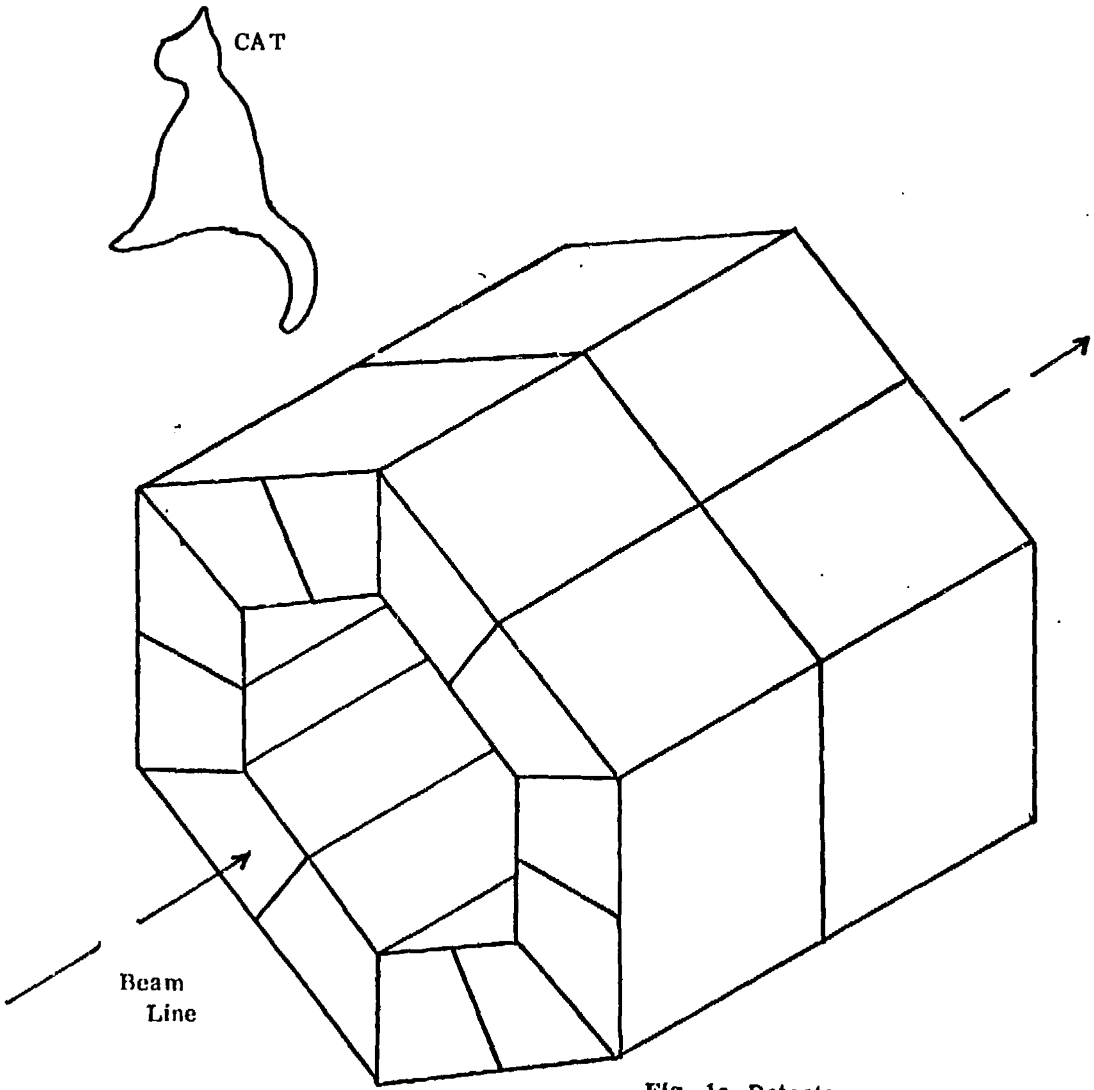

Fig. 1a Detector

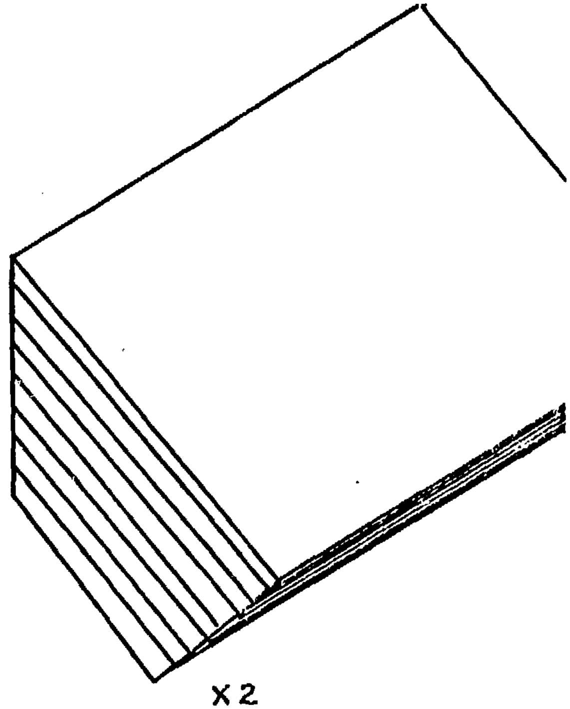

Fig. 1b Detector Section