2cp
RECEIVED BY TIC SEP - 5 1972

BROOKHAVEN NATIONAL LABORATORY
Associated Universities, Inc.
Upton, New York

ACCELERATOR DEPARTMENT
Informal Report

NEW PARTICLE SEARCHES AND HIGH TRANSVERSE MOMENTUM EVENTS

Charles Peoples

January 25, 1972

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

NEW PARTICLE SEARCHES AND
HIGH TRANSVERSE MOMENTUM EVENTS

John Peoples *

National Accelerator Laboratory and
Laboratory for Nuclear Studies, Cornell University

I. Introduction

The promise of very high energy and luminosity that ISABELLE offers, opens the possibility for the discovery of new particles. The most likely candidates for new particles include the intermediate vector bosons of weak interactions, the massive photon which renders QED finite, additional massive leptons and quarks. Lederman and Willis have each discussed a type of experiment which could be used to search for all of these particles except the last mentioned.^{1,2} Each experiment relies on the likelihood that these new particles have very large masses and short lifetimes. Their decay products would emerge from the interaction region with large values of momentum perpendicular to the p-p collision line. Furthermore, they assume that a significant fraction of the decay modes will be leptonic or semileptonic. The separation of leptons from hadrons can readily be made by the differences in the way their energies are dissipated in matter. For example, all known particles except muons and neutrinos would be absorbed in the impactometer-calorimeter proposal of Willis.² A large transverse momentum imbalance would signal the presence of either a muon or a neutrino. In the proposal of Lederman, electrons would be distinguished from hadrons and other leptons by the fact that the energy of the former can be absorbed and measured in 20 inches of lead glass, while little happens to the latter in the same amount of material.

* Supported by the Alfred P. Sloan Foundation 1971-1972

If there are particles which correspond to the triplet representations of SU_3 as the baryons correspond to octets of SU_3 , these particles could conceivably be produced at ISABELLE. Little can be conjectured about these particles except that at least one is completely stable and that their masses are greater than 3 or 4 GeV/c^3 . They may or may not have fractional charge, for models can be constructed for both possibilities. It is almost certain that leptons would not provide a means of signalling the presence of these particles. Moreover the way in which these particles are absorbed is unknown. It is probable that they will not be absorbed as readily as hadrons and they will certainly be absorbed much more readily than muons. Thus it is doubtful that the schemes of Willis and Lederman will be useful in quark searches. For the purpose of discussion, I will call these triplets quarks without prejudice about their charge. Moreover, I will assume that their masses are 15 GeV thus putting them out of reach of NAL and the ISR. The purpose of this note is to point out that an experiment which is used to study particle production at 90° is a useful way of looking for quarks if the apparatus can measure momenta of twenty GeV/c . This in turn sets the length of the apparatus at about thirty to forty feet.

II. Quark Production at 90°

Why are large transverse momentum events a fruitful place to look for quarks? The results of deep inelastic scattering can be viewed as evidence for the existence of massive point-like structures in the nucleon, which are known to the trade as partons. Since quarks, if they exist, are a set of massive particles which can be combined to form nucleons in a way which would

lead to SU_3 symmetry, economy suggests that partons and quarks should be the same. It is likely that when a quark in one nucleon collides with a quark in another nucleon, isolated quarks will emerge only when the transverse momentum of each colliding quark is sufficiently large so that the wave functions of the colliding quarks are completely uncorrelated with one another and the other quarks in the nucleons. The virtue of going to 90° in the c.m. is that one may expect to find nonrelativistic quarks which have momenta much larger than the pionization background. For example, a quark of mass $15 \text{ GeV}/c^2$ with a kinetic energy of 2 GeV , has a momentum of $8 \text{ GeV}/c$. A kinetic energy of 2 GeV was picked for an example because it is just below the threshold of π production on nuclei by these quarks. Since β of this quark would be 0.47 , it would be very easy to measure β by time of flight over a distance 20 feet to 5% . If a magnet measurement of the momenta and the differential energy loss, dE/dx , are made at the same time the charge and mass of the quark could be determined. At small angles the quarks would tend to be relativistic and thus time of flight would not be useful. Moreover, the method of separating the background which will be proposed will be less effective.

In order to estimate the quark cross sections, let the following be assumed; the quarks are point-like and they interact with one another through the exchange of a virtual gluons. The differential cross section can be parameterized as

$$E_q \left(\frac{d\sigma}{dP_{11}} dP_\perp^2 \right) = \frac{4\pi\alpha^2}{(P_\perp^2 + M_q^2)^2} J_p(x_1, x_2)$$

$$x_1 = (P_q - P_2)^2 |s \quad x_2 = (P_q - P_1)^2 |s.$$

P_1 and P_2 are the 4 momenta of the colliding protons. The function $J_q(x_1, x_2)$ would be related to the joint probability distributions of the momentum distribution of the quarks in the protons, and the probability that a real quark will emerge from the scattered quark with a momentum P . In the limit of infinite energy one might expect that the quark multiplicity would grow logarithmically, as one believes the multiplicity will grow for all known hadrons. If this were the case the function $J_q(x_1, x_2)$ might be expected to be similar in magnitude to the functions tabulated in reference 4 for the case $p + p \rightarrow h + "x"$. At 90° in the c.m. the values of x_1 and x_2 are equal and given approximately by $+E_q/2E_0$. Thus even for $E_q \approx 20$ GeV, x_1 and x_2 are only $+0.05$, and $J_h(x_1, x_2)$ is of order 10^{-2} . If one assumes $\rho = 1$, a point which will be discussed in the next section, then the product of the cross section and the experimental aperture yields an effective cross section of $5 \times 10^{-34} \text{ cm}^2$.

$$\Delta\sigma = 4\pi p^2 \left(\frac{\Delta\Omega}{2\pi} \right) \int \frac{P_1}{E_q} \frac{1}{(P_1^2 + M_q^2)^2} J_q(x_1, x_2) dp_1^2 \approx \frac{\rho^2}{M_q^2} (\Delta\Omega) J_q\left(\frac{M_q^2}{S}, \frac{M_q^2}{S}\right)$$

$$\Delta\sigma = 1 \times 1.8 \times 10^{-30} \times (0.2) \left(\frac{0.4}{2\pi} \right) \times 2 \times 10^{-2} \approx 5 \times 10^{-34}$$

This leads to a rate of 5 quark events/second. If ρ is replaced by e_q^2 , the cross section would be similar in magnitude to that estimated in reference 3. This leads to about one event per hour. In either case, there is an observable production cross section.

III. Hadron Production at 90° at Large Momenta

Berman, Bjorken, and Kogut have proposed that inclusive cross sections for the process $p + p \rightarrow c + "x"$ will have to form⁴

$$E_c \frac{d\sigma^2}{dP_{\perp} dP_{\perp}^2} = \frac{4\pi\alpha^2}{(P_{\perp})^4} J(x_1, x_2) .$$

The function $J(x_1, x_2)$ and the coupling ρ^2 depend on whether c is a photon, a lepton, or a hadron. They argue further that this form should represent a lower bound to the cross return if ρ^2 is replaced by α^2 . For in this case one knows that the virtual photon spectrum of one of the protons will give rise to a process similar to deep inelastic electron scattering. If there is a bare parton-parton strong interaction one would expect ρ^2 to be of order 1, when c is a hadron.

If one examines the existing data when c is a proton or a pion and determines what bound it puts on ρ^2 , one obtains $\rho^2 \leq 1.4 \times 10^4$. The data is taken from reference 5 for $p + p \rightarrow p + x$. The maximum value of $P_{\perp}$ which this data includes is 2 GeV/c. At that value of $P_{\perp}$, x_1 and x_2 were 0.42 and 0.2 which corresponds to a value of $J(x_1, x_2)$ of 2×10^{-6} . This points out that the kinematics are very unfavorable for observing $P_{\perp}$ of 2 GeV/c at existing machines. At NAL the factor $J(x_1, x_2)$ will be small when $P_{\perp} > 5$ GeV/c, while at ISABELLE x_1 and x_2 can be made very small so that $J(x_1, x_2)$ does not suppress the cross section. On the basis of the apparatus described in the next section, the following rates are expected:

$(P_{\perp})$ max.	$\Delta\sigma_{\text{eff}} (10^{-32} \text{ cm}^2)$	Events/Hour ($\rho^2 = 1$)
5	0.2	7.2×10^6
10	0.01	3.6×10^5
20	5×10^{-5}	1.8×10^3
40	1.1×10^{-7}	4
80	4.7×10^{-10}	0.017

If ρ is about 1 the limit of sensitivity of this device is about 60 to 80 GeV/c. If $\rho = \alpha$, the limit is about 20 GeV.

Having established in some sense that there will be enough rate to justify an experiment, I will comment on some of the other objectives of such an experiment. When one of the parton scatters it will frequently have a large transverse momentum. If the energy of this parton is E , then Bjorken et al. expect the parton to evolve into a jet of hadrons with multiplicity $\ln(E)$.⁴ Relative to the scattered parton direction, the hadrons in the jet will have a transverse momentum distribution which varies as $e^{-6P_{\perp}}$. If this is so, the apparatus should be capable of measuring the mean multiplicity of a jet as a function of its energy. Furthermore, the composition of the jet is of great interest. For example, if a q is knocked out of a nucleon, the remaining quarks have wave functions which overlap. If the q - q binding is not very strong, the quarks may find it energetically feasible to decay into a $\bar{q}$ and a nucleon. This could give rise to a hyperon with large transverse moment. Other unusual processes can be thought of.

IV. Experimental Apparatus

The experiment consists of two gas Cerenkov counters, several sets of proportional wire chambers, a 48D48 type magnet, and a particle detector. The particle detector consists of a set of dE/dx counters, a set of shower detectors, and a calorimeter. The apparatus could be placed in either the small angle crossing or the colinear interaction region. The main constraint on the beam is that the interaction region cross section be less than or equal to 1 mm diameter, since this hypothesis is used in the momentum determination. The 48D48 magnet is assumed to have an aperture of

2' x 4' and its field is parallel to the p-p collision axis, as shown in Figs. 1 & 2. The charged particles are bent vertically. PWC(2) and PWC(3) are two sets of proportional chambers which have dimensions four feet by two feet and ten feet by six feet respectively. The wire spacing is 24/in. in PWC(2) and 12/in. in PWC(3). The momentum is measured by using the track direction and positions determined by PWC(2) and PWC(3) and the known location of the beam-beam interaction cross section, which is assumed to be 0.042" diameter. PWC(1) is used to check the consistency of the track, by requiring one of the points in PWC(1) to lie on the track. A discussion of the accidental rate in PWC(1) is given later.

The momentum resolution of the magnet spectrometer when $\int B \cdot dl$ is 2500 kilogauss-cm will be 3% at 50 GeV/c for particles of unit charge.

$$\frac{\delta P}{P} = (0.03) \left(\frac{P}{50} \right) \left(\frac{2500}{B \cdot d} \right) \int_q^{-1} \text{(RMS)}$$

P is in GeV/c

$\int B \cdot dl$ is in kG-cm

$\int_q$ is the charge in units q of the electron charge.

The length of the magnet spectrometer is 20 feet. The dE/dx counter has a depth of 6 inches. The shower detector is used to measure γ rays from π_0 's and directly produced electrons. It has a depth of 2 feet. The calorimeter consists of 16 modules between each module there is a set of conventional wire chamber planes. Each module is made up of two 3" slabs of steel interspersed between scintillating material. The calorimeter length is estimated to be 16 feet long. The energy resolution of the calorimeter for hadrons is estimated to be 10% rms at 30 GeV. At other

energies it is given by

$$\frac{\delta E}{E} = 3 \cdot \left(\frac{1}{30E} \right)^{\frac{1}{2}} \quad E \text{ is in GeV}$$

The addition of chambers and the fineness of the calorimeter is due in part to the desire to provide a nuclear target and observation apparatus for quark-nucleon scattering if quarks exist.

Time of flight is measured by the time difference between one of the counters A_i , a row of twenty-four 1" x 1" scintillation counters, and the dE/dx counters. The time of flight between each A_i and the dE/dx counter is measured for each event. In addition, there are trigger scintillation counters after PWC(2). Cerenkov counter C_1 will have a 6 foot radiator and will be a high pressure counter. C_2 will operate at 1 atmosphere and will essentially be a rubber bag of variable dimension. Separation of π , K, and P will be possible over most of the momentum range from 300 MeV/c to 30 GeV by using combinations of Cerenkov counters and time of flight.

Two problems which are worth discussing are the counting rates in various parts of the detectors and the background from the beam gas interactions. The counters, A_i , and the proportional chamber, PWC(1), see all the pions produced within an azimuthal angle ϕ of ± 0.25 radians. The acceptance of PWC(1) corresponds to roughly ± 0.2 in the rapidity variable, w . The flux of particles in PWC(1) is then

$$f = (L) \left(\frac{d\sigma}{dw} \Delta w \frac{\Delta\phi}{2\pi} \right) = (2 \times 10^{34}) (32 \times 10^{-27} \times 0.4 \times 0.5/2\pi) = 2 \times 10^7/\text{sec}$$

Since the flux is spread out uniformly over an area of 2 square feet, the counting rate per wire is less than $1.4 \times 10^5/\text{sec}$. Since the PWC(1) is only used to establish that at least one point is on the track this rate is satisfactory. The counters A_i each subtend 1/24 of the solid angle of PWC(1). Consequently, the rates in A_i are individually about 8×10^5 which is an

acceptable rate. Time of flight is measured by measuring the time of arrival of each A_i to a reference time separately. This is also done for each dE/dx counter separately. The reference time is defined by the OR of counters B_i . The flux of particles emerging from the magnet is less for two reasons; the acceptance in rapidity is only ± 0.1 and the magnetic field sweeps low momentum particles away from PWC(2) and B_i . The minimum momentum which can reach PWC(2) when $\int B \cdot dl$ is 2500 kG-cm is greater than 700 MeV/c. The effective cutoff is about 1.0 GeV/c which leads to a further reduction of a factor of 50. Therefore the counting rate in PWC(2) and the sum of B_i is expected to be $2 \times 10^5/\text{sec}$. The counting rates in PWC(3), dE/dx , and the calorimeter will be smaller by at least another order of magnitude.

The effect of beam-gas scattering will be small for the following reasons:

(1) With the exception of the particle identification detector, the apparatus is only sensitive to particles emitted at large angles to the beam near or in the interaction region.

(2) Beam-gas interactions which produce secondaries which strike the particle identification detector and which can come from the full 200 meter straight section can be reduced by covering the beam pipe with a 6 inch iron belt. If this is done only muons will emerge and the calorimeter is not particularly sensitive to them.

Assuming that the residual beam gas is H_2 at a pressure of 10^{-10} torr,⁶ the total interaction rate in the 200 meter straight section is 6×10^6 . The total number of pions which can decay before striking from the shielded beam and which subsequently emerge from the shielded beam pipe is reduced by at least a factor of 10^{-2} . If the solid angle of each portion of the apparatus is

included, the counting rate due to beam-gas interactions will probably not exceed $10^4/\text{sec}$.

V. Conclusion

The conclusions which can be drawn from this exercise is that large transverse momentum physics may well be interesting and if one is to prepare for its exploitation at least forty feet of space must be allowed perpendicular to the beam line. This space need only extend forty feet along the beam line. Thus the proposed structure needs only a bulge near the intersection region.

References

1. L.M. Lederman "Large Q^2 Experiments at Isabelle," CRISP 71-29
(ISABELLE Project) Brookhaven National Laboratory.
2. W. Willis (a CRISP note which is to be published).
3. J. Sculli and T.O. White "Quark Pair Production in Proton-Nucleus Collisions," PRL 619 Vol. 27 (1971). References to previous work on quark production calculations and searches is contained in this reference.
4. Berman, Bjorken, and Kogut, SLAC Preprint, Aug. 1971 (SLAC - Pub.-944).
5. Anderson, et al., Proton and Pion Spectra from Proton-Proton Interactions at 10, 20, and 30 BeV/c. Physical Review Letters 198, Vol. 19, No. 4 (1967).
6. P. Grand, "Vacuum System Parameters for Isabelle," CRISP 71-38
(ISABELLE Project).

BY..... DATE.....

SUBJECT.....

SHEET NO..... OF.....

CHKD. BY..... DATE.....

JOB NO.....

DEPT. OR PROJECT.....

Fig 1.

VERTICAL PROJECTION.

Scale 1/4" = 1'

BROOKHAVEN NATIONAL LABORATORY

BY _____ DATE _____ SUBJECT _____ SHEET NO. _____ OF _____
 CHKD. BY _____ DATE _____ JOB NO. _____
 DEPT. OR PROJECT _____

FIG 2 - HORIZONTAL PROJECTION