E-609--STUDY OF HIGH p_T EVENTS

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Introduction

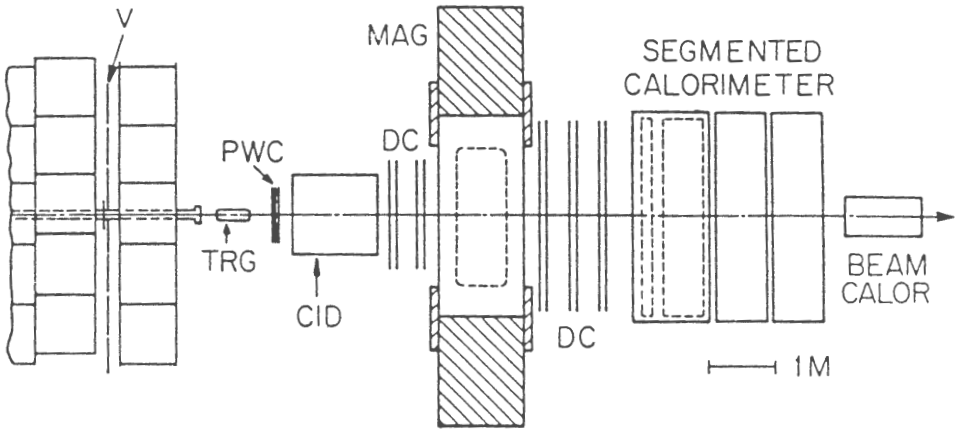
The existence of hadron jets at high p_T was first predicted by Bjorken in 1972. Bj reasoned that the partons observed in deep inelastic scattering could produce interactions at high p_T in hadronic collisions giving rise to jets of particles at large angles with respect to the beam. He suggested that the study of these collisions in a calorimeter would provide valuable information concerning the interactions of the partons and the structure of hadrons. Since that time the theory of QCD (quantum chromodynamics) has been developed. This theory of strong interactions can be used to predict the expected jet cross-sections and the evolution of the hadron structure functions. Several experiments have now reported the observation of jets at the ISR and the SPS Collider. We report here the first measurements of jets at Fermilab energies.

Physics

The principal objectives of E-609 were initially (1) to study di-jet cross sections and to compare them with theory, and to study (2) the possibility of parton identification in jets, using both charge and mass identification of the leading fragments in jets, (3) meson structure functions, and (4) high-p_T phenomena involving nuclear targets. By the time the first run took place in 1982, other large-solid-angle calorimeter studies of high-E_T events had been carried out at the SPS and at Fermilab. These experiments showed that a trigger using simply the total transverse energy E_T gave events that were mostly not of di-jet character, although some of the events detected did appear to be jet-like. We therefore made our first priority the study of how clearly di-jets could be seen, at Fermilab energies, and the investigation of the efficiency of different triggers for selecting such events in an unbiased way.

Apparatus

The principal part of the apparatus shown below was a highly segmented calorimeter array, with transverse segmenting into 132 "towers" pointing roughly at the target and



Layout of apparatus for E-609.

covering 9 srad at 400 GeV. Each tower consisted of 4 layers in depth; the first sample was a few radiation lengths thick, and the following 3 provided a total thickness of 6 to 8.2 absorption lengths. Sampling thickness was fitted to the lab energies expected for individual particles, and provided fine sampling for the 1 to 2 GeV particle energies that are significant at the outer angles, and at the same time coarser sampling, with small shower size and large total absorption thickness, for the 100 to 200 GeV particle energies encountered at the inner angles.

Triggering was accomplished with a very flexible triggering system which allowed simultaneous collection of data with many different kinds of high-p_T and high-E_T triggers.

The apparatus also included 15 wire-chamber planes, a large-aperture magnet, and a beam calorimeter. The magnet was operated with a small momentum kick, which allowed useful momentum and charge-sign measurements while not appreciably disturbing high-p_T triggering. The beam calorimeter allowed the study of possible novel processes, such as the Berger-Brodsky process in which a meson can be totally absorbed in a high-p_T collision, leaving no beam jet. (Data were taken in the 1982 run with incident mesons as well as protons; unfortunately, no meson beam was available in the 1983-84 run.)

A large solid-angle ring-imaging Cherenkov counter to identify outgoing particles was also installed for part of the 1982 run for test running. Initial results offered promise for

further operation, but unfortunately, a special image intensifier burned out shortly before the 1983-84 run.

Performance of Beam and Detector

Experiment 609 was approved in 1978 and was initially expected to run by late 1980 or early 1981. In fact, the first running was delayed by accelerator problems and was scheduled for January 1982. Because of severe problems in the M6 superconducting beam line, very little running was obtained in the 1982 run. A further run was therefore scheduled for 1983-84 and took place, with relatively little trouble, during the 400-GeV break-in period of the Saver.

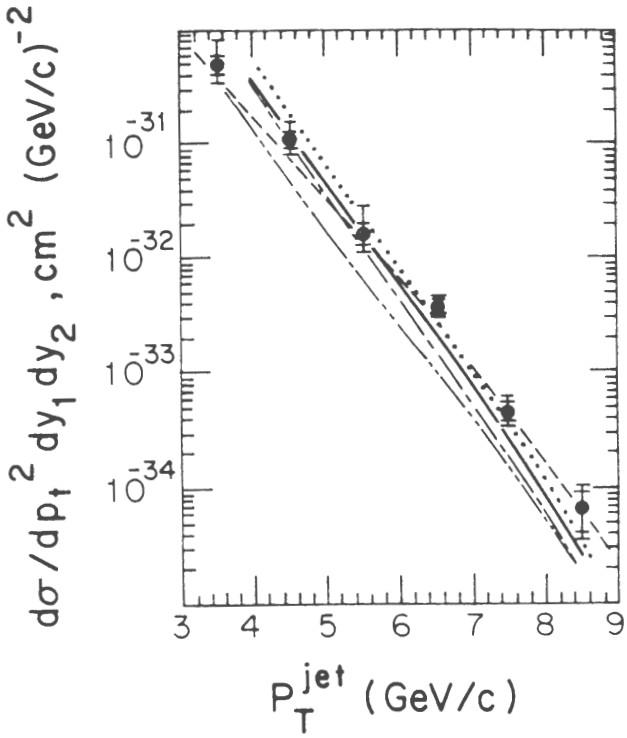
For the 1983-84 run, the electronics was put into defect-free condition, and additional extensive monitoring procedures were set up to make sure the 528-tube calorimeter system would operate smoothly and stably throughout the run--and it did. The new M-West beam line operated very smoothly, almost without trouble. Finally! The Saver operated on the whole quite well, though there were rather severe difficulties with beam-spill structure which were just beginning to be brought under control as the run approached its end. These spill problems may have been associated with the special pinhole collimator which is a part of the MT beam line. The beam optics for 400 GeV were highly improved over those of the 1982 beam. This permitted us to run at several times higher instantaneous intensity than we could have used in the earlier run. Since the spill time per minute was also several times higher than in the 1982 run, we were able to operate with 10 to 15 times as much flux per hour as in 1982. We also had 2 to 3 times as many good data hours, and thus in total obtained some 30 times as much integrated luminosity as in the 1982 run. This enabled us both to reach to substantially higher p_T than in the 1982 run and at the same time to allot considerably more time than in 1982 to running with nuclear targets.

Results So Far

Immediately following the 1982 run we were able to analyze the data to a sufficient degree to show in a model-independent way that a signal of di-jet like events could be seen at Fermilab energies, and we gave a report on these results at the Paris High-Energy Conference. The first dijet events from the CERN SPS Collider, which were visually spectacular, were also reported at the Paris Conference. In addition, the ISR experiment R807 also reported the calorimetric observation of jets.

The 1982 data have now been analyzed in detail to obtain di-jet cross sections at 400 GeV, using one trigger that showed itself to be particularly efficient at selecting di-jet events in an unbiased way while discriminating strongly against "soft"

events that have high E_T but no clusters of high-p_T particles. This is the "2-high" trigger, which requires that any 2 or more towers give p_T signals above a threshold, typically set at about 1.25 GeV/c. The cross-section results shown below are in strikingly good agreement with the calculations from pertubative QCD,



Dijet cross sections: data points from this experiment, curves from various QCD theoretical calculations.

especially considering the 7% uncertainty in energy scale. (The curves in the figure correspond to theoretical calculations using 5 different sets of structure functions proposed by various authors.)

Fixed-target high-p_T experiments allow the study of two types of reactions not presently accessible with colliding-beam machines, reactions using incident mesons, and reactions using nuclear targets. In the 1982 run we took data on both of these reactions. The 2-high trigger enables us to select jet-like events, even with nuclear targets, and to study their A-dependence, which proves to be substantially different from

that of non-jet-like high-E_T events. The preliminary nuclear target results appeared interesting enough that for the 1984 run we prepared and carried out a much more detailed set of measurements, using targets ranging from liquid helium to lead. When analyzed, these measurements may shed some light on the detailed nature of the space-time hadronization of scattered high-p_T partons, as well as on the nature of very high multiplicity events having large transverse energy and no jet structure.

The data taken in the 1982 run with mesons have also been under extensive analysis. We are now nearing the completion of analysis both on pion structure functions and on the search for the novel Berger-Brodsky type events.

The 1984 data were closely monitored, with continuous sampling by off-line analysis during data taking, and we believe they are of very good quality. The data have been put through the necessary analysis to reach the data-summary-tape stage, and DST's are being prepared. Eight graduate students have worked on E-609; one has finished his work and received his Ph.D.

Future Plans and Final Remarks

Intensive analysis of the E-609 data is in progress, by a number of members of the more advanced staff and by the students. On a longer time scale, many members of the collaboration are also at work on several new experiments. Most of the E-609 equipment will be used in the jet photoproduction experiment E-683, and many members of E-609 collaboration will participate in that experiment. Other members of the E-609 collaboration are at work on the $\bar{p}p$ collider experiments E-740 (D-0) and E-735 (search for quark-gluon-plasma effects), and on a large nucleon-decay experiment.

Like many other recent experiments at Fermilab, E-609 was delayed years beyond an optimum schedule. Some of the physics results that have come and will come from this experiment, like the di-jet cross sections, would have been a good deal more novel if they had come several years earlier, but are significant even with the delay. We expect that some of our forthcoming results will be unique and very interesting in spite of the delay.

Our experience in this experiment suggests that for efficient use of the accelerator and minimum experiment delays, in the coming years when collider and fixed-target running periods must both be provided, extensive pre-testing of beam lines, PREP electronics, detectors should be allowed for in the schedule. The Laboratory needs increased test-beam facilities for this purpose, as well as an increase in PREP and in on-line computer facilities.

We are glad to have had the opportunity to have a good run with the Saver. The Saver performance was very impressive, and

the support of the Laboratory, particularly through the newly organized Experimental Areas Department, was of crucial importance and great effectiveness. Our thanks to you all!

Snoopy, with the help of Alan Guth, particle theorist/cosmologist from MIT, ponders the Inflationary Universe.

Particle Experimentalist, Frank Sciulli, from Columbia University, gave a review on Neutrino Mass/Oscillation Experiments.

From east, west, north, and south they came: (foreground left to right) Larry Abbott, Brandeis University, Steve Ellis, University of Washington, and Pierre Sikivie, University of Florida.

Nobel Laureate Steven Weinberg from the University of Texas spoke about extra dimensions.

(Photographs by Fermilab Photo Unit)