LEPTONS AND HADRONS AT HIGH TRANSVERSE MOMENTUM--EXPERIMENT 605

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Introduction

In 1979, E-605 was proposed and approved to extend to Tevatron energies the measurements of the previous Proton Area Experiments 288 and 494. Now, in 1985, E-605 is the first large new facility designed and built specifically for Tevatron energies to reach the end of its approved program. In the last few years this experiment has impinged directly or indirectly on most departments at Fermilab. The successful completion of our approved program despite the conflicting demands of the Tevatron construction programs is a testimony to the cooperation and diligence of the Fermilab staff. Although there is not room in this article to personally thank all those who have helped, their efforts are appreciated.

Physics

In 1977, E-288 reported the existence of an unexpected family of narrow resonances, the Upsilon family, in the dimuon mass spectrum from 400 GeV proton-nucleus collisions. Before the experiment was dismantled in 1979, it had mapped out the production of massive dimuons by the Drell-Yan mechanism and had observed the three narrow upsilon states. Experiment 494 had converted the E-288 spectrometer for dihadron measurements by adding threshold Cherenkov counters. Both experiments were limited in their ultimate luminosity by the copious flux of muons emanating from the beamstop between the spectrometer arms. Experiment 288 was further limited by the 2 % resolution of the spectrometers. The 500-MeV splittings of the three upsilon states, combined with a poor resolution, tend to obscure the whole region from 8.5 GeV to 11 GeV. Nevertheless, both experiments opened new vistas in quark-quark scattering, quark-quark annihilation, and lepton production at high transverse momenta.

There remained many questions that could be better addressed at Tevatron energies. Did the anomalous atomic-number dependance of hadron yields at high p_T persist to higher energies? Did the

energy dependance of quark scattering and lepton production follow QCD predictions? Were there more narrow states in the high-mass region hidden beneath the dominant S-state upsilon resonances? The E-605 spectrometer and the new M-East (ME) external proton beam (ME) were optimized to answer these questions.

Apparatus

A high intensity, clean, carefully focussed external proton beam was the first requirement of the proposed experiment. The new ME beam uses a dozen 3Q120 quadrupoles and sixteen Energy Saver dipoles to transport beams of up to 1 TeV to the E-605 spectrometer in the Meson Detector Building. The quads form a FODO channel with a final-focus section yielding a 0.01-in. high by 0.1-in. wide spot at the spectrometer target. The beam has proven very reliable and stable, and has a halo of less than 10^{-6} outside a 3-in. beam pipe. It has transported 4×10^{12} protons/pulse at 800 GeV. The beam is somewhat unique in the experimental areas as it has no windows and a sub-micron vacuum for its entire length.

The backbone of the E-605 spectrometer is two large analyzing magnets. These magnets were assembled from iron salvaged from the Nevis Cyclotron at Columbia University. The first magnet, 50 ft long with a horizontal gap of 36 in. and a vertical pole width of 48 in., has 65-ft long aluminum coils which were fabricated at Fermilab (TM-1034 Fermilab). The second, a re-analyzing spectrometer magnet, has a horizontal gap of 59 in., a vertical pole width of 66 in., and a length of 13 ft. The coils for this magnet were assembled from the same aluminum conductor by Sumitomo Corporation of Japan under the aegis of the Japan/US Collaboration.

The beamline and the water-cooled copper beam dump in the first spectrometer magnet are designed to accept the full intensity of the slow-extracted proton beam from the Tevatron.

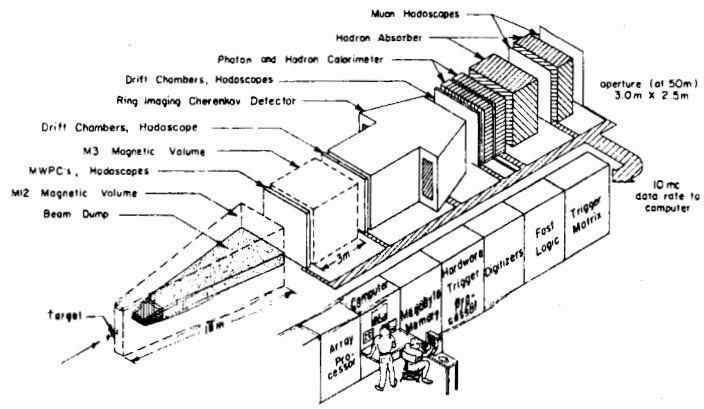
The spectrometer shown schematically at right is instrumented to detect and identify all charged hadrons and leptons. The small-cell drift chambers (16 planes, 2500 wires) and the MWPC system (6 planes, 5000 wires) were built by the Fermilab Physics Department. The proportional-tube muon detectors were built at the University of Washington. The electronics for the chambers were built by Columbia University and the Japan/US Collaboration.

The scintillator hodoscopes and the fast-matrix electronics comprising the first-level trigger were built by Stony Brook and Washington. The second-level trigger system involved a large electron-hadron calorimeter built by Kyoto, and a sophisticated trigger processor built by Columbia (IEEE, N531, 5 (1984), 1028.)

and the Japan/US Collaboration. This processor searched for tracks in the chambers which pointed to the target and not the beam dump.

Particle identification is completed by the ring-imaging Cherenkov counter. The counter employs a radiator of ultra-pure helium gas and two multi-step photon detectors sensitive to far ultra-violet Cherenkov protons which photoionize triethylamine (TEA). This detector was developed by CERN, Saclay, and Stony Brook (FN-375 Fermilab). It has a 90-GeV threshold for protons and can separate pions and kaons up to 300 GeV over an input angular acceptance of ±100 mrad.

Fermilab 605 Precision Spectrometer for High P_T Particles.
Fermilab, StonyBrook, University of Washington,
Columbia, Saclay, CERN, Kyoto, KEK.



Schematic view of the E-605 spectrometer.

The 10 MHz data acquisition "Transport Bus" developed at Columbia University deposits data during the spill into a 4-Megabyte dual-port memory developed at the University of Washington. Data logging to tape, equipment monitoring, experiment control, and the link to a VAX 780 are handled by the University of Washington PDP 11/45 Data Acquisition System. The full system can handle 4 Megabytes of data in a 20 second spill with negligible deadtime.

Data Taking

The spectrometer was assembled in the new ME area of the Meson Detector Building during the first four months of 1982. The old, conventional M1 beam was upgraded for 400 GeV high-intensity operation and commissioned during a spring 1982 shutdown. During April and May the beamline and spectrometer were debugged.

Initially, the background rates through the open aperature into the detectors were much higher than design estimates. Nevertheless, after careful work on collimation of secondary sources within the large analyzing magnet, two weekends of data were recorded at an intensity of 2×10^9 protons/sec. The atomic-number dependence of hadron yields was studied and the analysis of these results will be published shortly. The 1982 test run was successful and uncovered the design modifications necessary for high-intensity Tevatron operation.

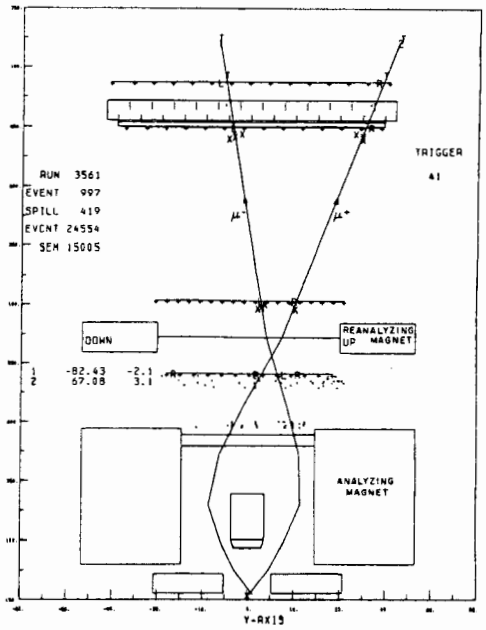
During the 1983 Tevatron installation shutdown, many design modifications were made to the E-605 spectrometer. In addition, the new ME beamline was assembled. Extensive work was done changing the configuration of the production target and tungsten absorber teeth in the large analyzing magnet. These changes included moving the target upstream and adding a small (BM105) pre-analyzing magnet in anticipation of 800 GeV operation.

In January and February of 1984, data taking on the production dynamics of hadron and dihadron yields at 400 GeV was completed using the newly commissioned Tevatron accelerator. In the spring of 1984 these measurements were extended to 800 GeV. In addition, a liquid hydrogen/deuterium target was installed along with the beryllium, copper, and tungsten targets allowing a full investigation of A-dependance effects. Even at 800 GeV, the many collimation improvements allowed operation at an intensity of 10^{10} protons/second in the open aperature configuration.

Preliminary results from this huge collection of open aperature data should be available this summer. Meanwhile, tests in June 1984, and modifications during the subsequent months, have led to a new maximum luminosity, closed aperature configuration.

During the present FY85 accelerator operations, the spectrometer has been optimized for the detection of dimuons. A 4-ft thick wall of lead has been added at the exit of the first spectrometer magnet, followed closely by a precision, high-rate proportional-tube detector. This allows a separation of the momentum determination in the second spectrometer magnet from the plane of multiple scattering in the Pb wall. Both a resolution of 20 MeV in mass at 10 GeV and a large increase in luminosity can be obtained.

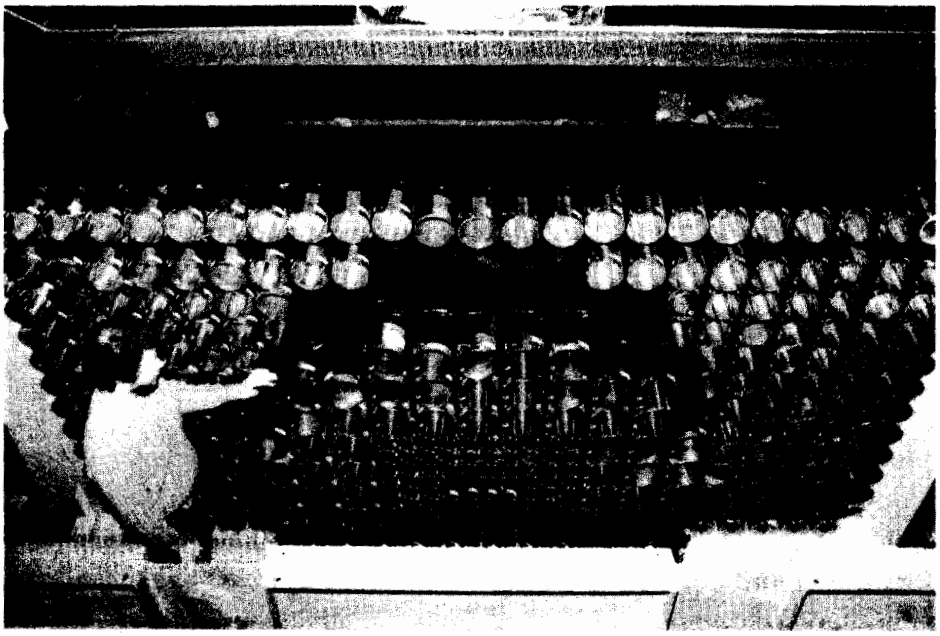
As this article is being written, the apparatus is recording dimuons produced by 800 GeV protons at intensities up to 2×10^{11} protons/sec. The events are surprisingly clean and easy to analyze, as shown at right. Any narrow states between 8 GeV and 20 GeV will be observed if their production cross section times branching fraction into dimuons is greater than 1% of the upsilon 1S resonance. Data on the systematics of dimuon production at 800 GeV via quark-antiquark annihilation (the Drell-Yan mechanism) are a byproduct of the measurement.



On-line computer display of a dimuon event from 1985 run.

Future

The original E-605 proposal included discussions of repeating all the above measurements with an incident pion beam. The design of a high-intensity pion beam in ME does exist. The E-605 collaboration plans on completing most of the analysis of the present data set before proposing further data taking. What is already clear is the beautiful performance of the ME beam and the E-605 spectrometer. The apparatus has been able to detect and identify hadrons and leptons almost up to the transverse momentum kinematic limit as originally proposed. The analyzed data set will surely suggest many future measurements.



Chuck Serritella (Physics Department) admires the just-completed stack of 576 glass blocks that make up the electromagnetic calorimeter for E-705. The shorter blocks on the outside of the array are made of lead glass; the longer blocks on the inside are made of a new scintillating glass which has superior resolution. The array, which weighs 30 tons, sits on a movable table that can position each of the individual blocks onto the beam line. (Fermilab photograph 85-161-18)