Experiments in the 1990 Tevatron Fixed-Target Physics Program†

E-665 Muon Scattering with Hadron Detection at the Tevatron
(Spokesperson: H. E. Montgomery)

ANL, U.C./San Diego, Fermilab, Freiburg (Germany), Harvard, Illinois/Chicago Circle, INP Krakow (Poland), Maryland, M.I.T., Max-Planck (Germany), Washington, Wuppertal (Germany), Yale

The experiment, which is located in the Neutrino Area Muon Beam, studies the interactions of muons with beam energies up to 750 GeV in various targets and with the capability of making detailed measurements on the recoil hadrons that emerge from the collision vertex. The collaboration has combined large magnets, the CERN Vertex Magnet (CVM) and the Chicago Cyclotron Magnet, in a spectrometer that will be as powerful as any known. The experiment took data for the first time during 1987-88 using deuterium, hydrogen, and xenon targets, and will continue these measurements in the 1990 fixed-target running period.

E-672 Study of Hadronic Final States in Association with High-Mass Dimuons (Spokesperson: A. Zieminski)

Caltech, Fermilab, IHEP, Serpukhov (U.S.S.R.), Illinois/Chicago Circle, Indiana, Louisville, Michigan/Flint

The aim of E-672, an open-geometry dimuon experiment, is to study production of particles produced in association with ψ and high-mass dimuon pairs. The experiment shares the Meson West beamline, magnetic spectrometer, and calorimetry with E-706. Physics goals include studies of hadrons and gammas produced in association with dimuons and a study of the A-dependence of ψ and Drell-Yan pair production with proton and pion beams. The first test/physics run of the experiment took place in 1987/88.

**E-683 Photoproduction of High P_t Jets (Spokesperson: M. B. Corcoran)**

*Ball State, Fermilab, Houston, Iowa, Lehigh, Maryland, Michigan, Rice, Texas/Austin, Vanderbilt, Wisconsin*

Experiment 683 is studying the photoproduction of high $p_t$ jets in the Wide Band Beam of the Tevatron. The quantum chromodynamics (QCD) processes of interest are QCD Compton scattering $gq \rightarrow gq$ (which dominates at high $x_t$), and quark-gluon fusion $gg \rightarrow qq$. These processes are very distinctive, with the photon coupling as a point particle, giving all its energy to the two high-$p_t$ jets, and producing no beam jet. The three-jet topology allows the separation of the direct-coupling processes from vector-meson-dominance-type processes, which produce the four-jet topology familiar in pp and $\pi p$ interactions. Due to the lack of a beam jet and the large energy in the parton-parton frame, these jet events are expected to be very clean compared to jets produced in a $\pi$ or p beam. The collaborators will measure the cross sections of both three-jet and four-jet events as functions of $x_t$, $p_t$, and $y$, and compare them to QCD calculations.

**E-687 Photoproduction of Charm and B (Spokesperson: J. Butler)**

*U.C./Davis, Colorado, Fermilab, Illinois, INFN/Frascati (Italy), INFN/Milano (Italy), Milano (Italy), North Carolina, Northwestern, Notre Dame, Pavia (Italy)*

E-687 is a photoproduction experiment in the Wide-Band Photon Beam of the Proton Area. Interactions of photons whose energies are typically above 200 GeV are analyzed in a multiparticle spectrometer. The physics goal of the experiment is to reconstruct large samples of particles containing heavy quarks, charm and bottom, in order to study the dynamics of heavy quark photoproduction, to carry out detailed studies of the weak decays of charmed mesons and baryons, to study the decays of particles containing B-quarks, and to study $J/\psi$ and upsilon photoproduction.

In the first run of the experiment, in 1987-88, over 70 million events were collected. These are now being analyzed. For the next running period, the beam intensity is being approximately tripled by using a liquid deuterium production target and transporting simultaneously a positron beam which will produce additional photons.

**E-690 Study of Charm and Bottom Production (Spokesperson: B. Knapp)**

*Columbia, Fermilab, Guanajuato (Mexico), Massachusetts, Texas A&M*

The primary purpose of this experiment, located in Neutrino Area - East, is a detailed, accurate study of the production and decay of charm and bottom par-
particles. The experimenters will concentrate on fully reconstructed events, for which all final state particles have been accurately reconstructed.

The experiment measures charged particles with a two-magnet spectrometer using drift chambers with small cells. This detector can measure complicated reactions, accurately and efficiently, at rates above $10^6$ interactions per second. The readout electronics, including pipelined digital computation hardware, permits detailed numerical reconstruction of $10^5$ events per second with little dead-time. A distributed hierarchy of trigger decisions can select any subset of raw data and calculations for transfer to an online computer and its tape drive. The high-rate capability of the detector and its associated event reconstruction hardware permit rare phenomena to be studied with high statistics, with trigger specificity and complexity normally reserved for tedious offline analysis.

**E-704 Experiments with the Polarized Beam Facility** *(Spokesperson: A. Yokosawa)*

ANL, CEN-Saclay (France), Fermilab, IHEP-Serpukhov (U.S.S.R.), Hiroshima (Japan), Iowa, KEK (Japan), Kyoto Sangyo (Japan), KyotolEducation (Japan), LAPP-D'Annecy (France), LANL, Northwestern, University of Occupational and Environmental Health (Japan), Rice, Trieste (Italy), Udine (Italy)

Experiment 581 obtained initial data on the properties of the new polarized beam. Completion of a 200-GeV/c conventional-magnet beamline allowed the observation of polarized protons and polarized antiprotons from decaying lambdas and antilambdas, respectively. A beam-tagging system and two polarimeters, using the Primakoff effect and Coulomb-nuclear interference, measured the beam polarization during the 1987-1988 TeV II period. Measured beam polarization was consistent with the designed value.

Experiment 704, in the Meson Area Polarized Proton Beam, continues E-581's work by simultaneously performing substantial parts of previously proposed experiments 674, 676, 677, and 678. The experimenters are exploring the spin dependence of the interactions in a global way using a straightforward experiment measuring the difference in pp and $p\bar{p}$ total cross sections between the states with helicities of target and beam parallel and antiparallel. A longitudinally polarized-proton target in a superconducting solenoid is being used with the polarized beam.

Studies of the inclusive production of neutral pions around $x_F = 0$ and large $p_T$ of neutral and charged pions at large $x$, and of $\Lambda^0 (K^0)$ and $\Sigma^0$ at large $x$ are being carried out simultaneously. These measurements will investigate the spin effects as a function of $x_F$ and $p_T$. 
E-706 A Comprehensive Study of Direct Photon Production in Hadron Induced Collisions (Spokesperson: P. Slattery)

Delhi (India), Fermilab, Michigan State, Minnesota, Northeastern, Penn State, Pittsburgh, Rajasthan (India), Rochester

Experiment 706 (situated at Meson Area - West) is studying the gluon structure functions of hadrons, and investigating gluon fragmentation, through analyzing the production of direct photons and their accompanying hadrons in collisions of pions, kaons, and protons with a variety of nuclear targets. At the constituent level, the reactions to be investigated are $qg \rightarrow q\gamma$ and $qq \rightarrow q\gamma$. The experimenters are also interested in carrying out an essentially unbiased comparison between the two fundamental quark-antiquark annihilation reactions, $qq \rightarrow \gamma\gamma$ and $qq \rightarrow e^+e^-$, by studying, in a single experiment, the relative yields of $\gamma\gamma$ and $e^+e^-$ triggered events. The experiment is to be carried out using 400- and 800-GeV/c protons and 530-GeV/c pions (both signs) using beam intensities $\geq 10^7$ per second.

E-760 Investigation of the Formation of Charmonium States Using the Antiproton Accumulator Ring (Spokesperson: R. Cester)

U.C. Irvine, Fermilab, Ferrara (Italy), INFN/Genova (Italy), Northwestern, Penn State, Torino (Italy)

Experiment 760, at the Antiproton Source Accumulator Ring, will study charmonium states formed in $pp$ collisions. E-760 will take data during the Tevatron fixed-target run; at the time that the Main Ring is not used as the injector to the Saver, 120-GeV protons will be targeted on the Antiproton Source target. The produced antiprotons will be accumulated in the Accumulator. After four hours of accumulation, the cooled antiprotons will be decelerated to the appropriate momentum (3 to 7 GeV/c) and the gas jet will be turned on. At this point a data taking run 20 hours long will commence. During the data taking period the stochastic cooling systems of the Accumulator will preserve the emittance and momentum spread of the stored antiprotons.

E-761 An Electroweak Enigma: Hyperon Radiative Decays (Spokesperson: A. Vorobyov)

CBPF (Brazil), Fermilab, IHEP/Beijing (P.R.C.), Iowa, ITEP (U.S.S.R.), LNPI (U.S.S.R.), SUNY/Albany, Sao Paulo (Brazil), Yale

Experiment 761 will probe the structure of the electroweak interaction and has two main goals. The first is to measure the asymmetry parameter for the electroweak decay $\Sigma^+ \rightarrow p\gamma$ and verify its branching ratio. The second goal will be to measure, or set new upper limits for, the branching ratio of the
Electroweak decay $\Xi^- \to \Sigma^- \gamma$. Since the $\Xi^-$ are expected to be polarized, information on the asymmetry parameter may also be available.

The experiment will use the Proton Center polarized charged hyperon beam and a new very-high-resolution spectrometer. In the March 1987 run, the experimenters tested their apparatus in Proton Center parasitically.

**E-771 Beauty Production by Protons (Spokesperson: B. Cox)**

*Athens (Greece), Brown, U.C./Berkeley, U.C./Los Angeles, Duke, Fermilab, Houston, Indiana, Lecce (Italy), MIT, McGill, Nanjing (PRC), Northwestern, Pavia (Italy), Pennsylvania, Prairie View A&M, Shandong (PRC), South Alabama, Virginia*

The presence of muons in final states produced in hadronic interactions has proved to be a valuable indicator that interesting hard physics processes have taken place. Experiment 771, in the Proton West High Intensity Laboratory, will use both high-$P_T$ single muons and high-mass muon pairs as a signature that events are possible beauty production candidates. These muons provide a mechanism for selecting the relatively rare beauty production from interactions due to the total cross section.

The experiment will use the high-rate E-705 spectrometer, which has already functioned well in experiments E-537 and E-705, to detect and measure beauty hadron decays which result in a final state containing either type of muon signature. E-771 will use the primary proton beam from the Tevatron at the maximum energy available at the time of execution of the experiment.

**E-773 Measurement of the Phase Difference between $\eta_{00}$ and $\eta_{+}$ to a Precision of 1/20 (Spokesperson: G. D. Gollin)**

*Chicago, Elmhurst, Fermilab, Princeton*

The goal of Experiment 773, in Meson-Center, is to measure $\Delta \phi$ to an accuracy of 1/20.

To avoid systematic uncertainties associated with imperfect knowledge of kaon beam flux, detector acceptance, and resolution-smearing effects, the experiment will measure $\pi\pi$ decays using a double-beam technique similar to that employed by E-731. One beam will pass through a thin regenerator at the start of the fiducial decay volume, while the other beam will traverse a thick regenerator 14 meters further upstream. The separation is chosen to make the $\pi_0\eta^*$ decay rate inside the decay volume insensitive to $\Delta \phi$ for $K_S$ from the upstream regenerator, and maximally sensitive to $\Delta \phi$ for $K_S$ from the downstream regenerator. The regenerators will switch beams between machine pulses. Data will be recorded simultaneously for $\pi_0\eta^*$ and $\pi^+\pi^-$ decays in both beams.
E-774 Electron Beam Dump Particle Search (Spokesperson: M. B. Crisler)
Fermilab, Illinois, INP/Krakow (Poland), Northeastern

The purpose of Experiment 774 is to search for light, neutral, short-lived particles that couple to the electron. The experiment will exploit the high energy and flux available in the Proton Area’s new Wide Band Electron Beam to probe this unexplored region. The search will be performed by positioning a neutral decay spectrometer downstream from the electron dump of the Wide Band Beam. A neutral particle coupled to the electron will be produced in the dump by a Bremsstrahlung-like process and will be observed by its decay in flight if its flight path is longer than the beam dump. The sensitivity of this method to short-lived particles is determined by the energy of the beam and the length of the beam dump. By using a short tungsten beam dump and the highest available beam energy, E-774 will extend the region of search by more than an order of magnitude beyond existing limits.

E-782 Muon Exposure in the Tohoku High Resolution Chamber (Spokesperson: T. Kitagaki)
Brown, Fermilab, IHEP-Beijing (P.R.C.), Indiana, MIT, Nagoya (Japan), Tohoku Gakuin (Japan), Tohoku (Japan)

The E-782 experimenters will carry out a muon experiment using the Tohoku High Resolution One-Meter Freon Bubble Chamber in the Neutrino Area NK Beam.

Physics goals are the study of: production of vector mesons, strange particles, and charm particles in a wide range of $Q^2$ down to $Q^2 \sim 0.1$ GeV$^2$; energy dependence of meson-baryon pair production in charm and strange channels; comparison of neutrino interactions and muon interactions in the same 4π detector; structure functions in the low $Q^2$ region down to $Q^2 \sim 0.1$ GeV$^2$ with small systematic uncertainty; and EMC effect. The new tagging method developed in E-745, using the nuclear debris, will be applied on the muon interactions.

E-789 B-Quark Mesons and Baryons (Spokespersons: D. M. Kaplan/J.-C. Peng)
Abilene Christian, Fermilab, LBL, LANL, Northern Illinois, South Carolina

Experiment 789 in Meson Area - East will study charmless two-body two-prong decays of neutral b-quark hadrons.
Under plausible assumptions for beauty production cross-sections and branching ratios to two hadrons, E-789 should record enough such decays to measure the lifetime of the \( B_d \) and possibly to discover the \( B_s \) and \( \Lambda_b \) and measure their lifetimes and masses. No other experiment now operating or under construction has comparable sensitivity. These measurements are essential to evaluating the suitability of dihadronic decays for the study of CP violation in the \( B \) system. In addition to dihadronic beauty decays, E-789 will have excellent sensitivity to dileptonic modes, allowing limits of order \( 10^6 \) to be set on their branching ratios.

**E-791 Hadroproduction of Charm and Beauty (Spokespersons: J. A. Appel/M. V. Puroit)**

*Columbia, Fermilab, IIT, Mississippi, Ohio State, Princeton, Tufts, Wisconsin, Yale*

Experiment 791, located in the Proton Area Tagged Photon Laboratory, aims to break new ground in charm and beauty physics. The experiment will run for \( 2 \times 10^6 \) spill seconds and write to tape 10 billion events, of which 125 million will contain charm. Extrapolating from the analysis experience of E-691 and E-769 using the same detector, the experimenters know that about 100,000 charm events will be fully reconstructed (10\( \times \) E-691's sample of 10,000 fully reconstructed charm events). It should be possible to reconstruct about 700 beauty events partially and perhaps 50 \( B \) events fully.

E-791 is simultaneously exploiting challenging new technologies. The vast number of reconstructed events is made possible by fast front-end electronics (<20 \( \mu \)s readout times), fast data acquisition, and high-speed writing to 8 mm tape (8Mbyte/sec). The second phase of the experiment will employ vertex and other triggers to enhance heavy flavors in the data even further.

**E-799 Search for the Rare Kaon Decay Mode \( K_L^0 \rightarrow \pi^0 e^+ e^- \) (Spokespersons: Y.-W. Wah and T. Yamanaka)**

*Chicago, Elmhurst, Fermilab, Princeton*

Experiment 799, at Meson Center (MC), will search for the rare kaon decay \( K_L^0 \rightarrow \pi^0 e^+ e^- \) with a sensitivity of \( \sim 1 \times 10^{-11} \). Theoretical predictions of the branching ratio range from \( 0.4 \times 10^{-12} \) to \( 0.6 \times 10^{-9} \). Within the Standard Model, this decay mode may have a sizable CP violating decay amplitude such that \( e^\prime \pi e/e \sim 1 \). A high-sensitivity search for this decay will test different models and provide a new window to explore the question of direct CP violation.
In the initial phase of the experiment, a 650-hour run of 2 x 10^{12} protons per spill (pps) with no change to the existing MC beamline and a modest upgrade of the E-731 detector, will yield ~1 x 10^{-10} sensitivity. A later run with 1600 hours of 3 x 10^{12} pps and a modest modification to the MC beam configuration will yield ~1 x 10^{-11} sensitivity.

**E-800 A Precision Measurement of the Omega Minus Magnetic Moment (Spokespersons: K. Johns and R. A. Rameika)**

Fermilab, Michigan, Minnesota, Rutgers

Experiment 800, located in the P-Center beamline, will measure the magnetic moment of the omega minus to 0.04 nuclear magnetons or better. This experiment is a follow-on to E-756, which pioneered a technique for producing polarized omegas, enabling a measurement of the omega moment to be made at the 10 percent level (about 0.2 n.m.). A precise measurement of the omega magnetic moment will provide valuable input to models of how quarks combine into hadrons and bring the omega precision in line with that of the other hyperons.

The magnetic moment of the omega is determined by measuring the spin precession of a polarized sample of omegas. Data from E-756 shows inclusively produced omegas from protons to have very little, if any, polarization. Instead of producing \Omega^-'s directly, E-800 will use 800-GeV protons to produce a secondary neutral beam of polarized A's and \Xi^0's, which is then used to produce a tertiary beam of polarized \Omega^-'s.
A New ACP Machine for Parallel Processing

by Richard Fenner

It wasn't quite "Mr. Watson, come here, I want you," but it was close. At 3 o'clock on the afternoon of August 4, 1989, several members of Fermilab's Advanced Computer Program (ACP) group gathered in their lab space on the 6th floor of Wilson Hall where dialogue was flashing across a computer terminal screen in response to keyboard entries. What they were watching was the first signs of life from a new standalone computer designed by the small band of synergists in the ACP group, headed by Tom Nash, as they quietly attacked one of the most vexing problems high-energy physics (HEP) faces in the immediate future: adequate computing capability for the analysis of millions of particle-interaction events. The new board, known as the ACP/R3000, had accepted the UNIX operating system and was ready to receive its first commands.

In 1983, the Ballam Committee, convened by then Fermilab Director Leon M. Lederman and empowered to assess future computing needs for high-energy physics, issued their report. It confirmed what had been suspected: The amount of computing capacity critical to future HEP experiments would far exceed the current capabilities. (That has certainly come to pass. For example, Fermilab Experiment 791 anticipates collecting 10 billion events during their next run.) Clearly, new computing strategies had to be found.

Various possible solutions were examined in light of realistic requirements such as expansibility and cost. At the urging of Nash, Lederman decided that the Laboratory would be able to design a special computer system that would go far in meeting Fermilab's computing needs. It would be a parallel processing computer built out of the currently best available hardware components. The basic idea, in the words of Mark Fischler of the ACP, was to "build the processor as inexpensively, and as lean and mean, as possible." That concept became the first-generation ACP parallel processor. It consisted of hardware and software combined into a rudimentary operating system, plus some user support from the ACP group. "We made that new computing power available to serious users who were willing to put up with the inevitable inconvenience of using something that is not the same as what everyone else was using," said Fischler.

A parallel processor is a computing engine consisting of several small processing units working simultaneously on different parts of a problem. This is opposed to a typical mainframe computer which processes data in series - very quickly, but one piece at a time. Under the ACP concept, one processor is as-
signed the task of parceling out different parts of the problem to many other connected processors. Each processor performs its discrete task simultaneously with the others. As each task is completed, a new problem is passed to a waiting processor.

The first-generation ACP was, at the time, 100 times more cost effective than any commercially available device. An ACP board that cost three to five thousand dollars was delivering the power of one half to one full VAX equivalent, which then cost approximately $250,000.

In spite of its "rudimentary" configuration, the first-generation ACP became a sought-after machine. Several experiments at Fermilab began using the ACP to analyze their events, and ACP's were ordered by the national laboratories at Brookhaven, Los Alamos, and Oak Ridge, as well as by SIN in Switzerland, Saclay in France, and CBPF in Brazil.

Since the advent of the first-generation ACP, the computer industry has continuously introduced new, improved chips, increasing the performance of processors by a factor of two each year. But the ACP group hasn't been idle, either.

The members of ACP set out to combine new higher performance processing units with more flexible and powerful software. The new processing unit, in the words of chief designer Hari Areti, is "a self-contained computer, incorporating the MIPS R/3000 microprocessor, the most cost effective chip currently available." Where the first-generation ACP provided one-half to one VAX equivalents, the new processor provides 15 VAX equivalents in the same amount of space at a similar cost. Depending on the amount of memory, this represents up to a factor of 20 increase in cost effectiveness. This computer, unlike the first ACP, supports a standard operating system, thereby broadening the potential user community. ACP chose the UNIX operating system because of its wide acceptance.

As Jim Deppe of ACP explained, "A key design element of the ACP/R3000 is that the entire processor fits into a single VME slot. This means that a single crate of ACP/R3000 boards can be loaded with more processors, producing more computing power per crate." Designing to VME slot tolerances gives the ACP/R3000 entree to widely used computing architectures. The new module consists of two boards. One, the "motherboard," is an 8-megabyte main memory board with a VME interface. On top of the main memory board, but still within a single slot dimension, is a plug-in "daughterboard" which contains the CPU and the instruction and data cache. The motherboard can also stand alone as a standard VME memory board with no processor, or as expansion memory for a CPU. "For example," said Deppe, "one could have a motherboard and
daughterboard combination and add additional motherboards in adjacent slots, increasing the memory to 16, 24, or 32 megabytes.

The new software, called cooperative processes software (CPS), is a set of tools which make it easier to divide up a computational task among multiple processors. "What we've done," said ACP's Joe Biel, "is considerably extend our range over the first-generation ACP." There, the emphasis was on hardware because there was a tremendous advantage to be gained from ACP hardware versus what was available from industry. "With this second-generation ACP/R3000," Biel continued, "we've done substantial software development in addition to new hardware. Unlike the old ACP software, which could only run on ACP computers, CPS is compatible with many other computers. The idea is that an experiment can mix and match - for example, buy Silicon Graphics machines and use CPS software, or use ACP/R3000 boards running CPS, or do both at the same time."

Universities Research Association, Inc., and Fermilab have entered into a commercial licensing agreement with Omnibyte Corporation, located in West Chicago, which will produce and market the ACP/R3000. In principle, any large computer center could use crates of the second-generation boards rather than their current computers, gaining computational power without a concurrent major dollar investment. According to ACP's Irwin Gaines, "Anybody who understands computers, has the kind of computational needs that lend themselves to parallel processing, and is looking for increased computational power at less cost, can use this machine."