anomalously high total E_T appears generally to be distributed quite uniformly among the particles emerging in all azimuthal directions.

If more attention had been paid to a pp scattering experiment performed a year ago at the (fixed target) SPS by a Bari, Cracow, Liverpool, Munich, Nijmegen collaboration,[4] Cline told us, the new high-E_T results from the p̄p collider would not have come as quite such a surprise. This lower-energy experiment had triggered on high-total-E_T events in the hope of studying jets in a segmented calorimeter that surrounded the entire 2π azimuthal range of the transverse plane. Unlike earlier experiments that had much more limited azimuthal coverage, this group found that the bulk of their high-E_T events had a non-jetlike uniform azimuthal distribution. The high-E_T event rate was much higher than that predicted by the simple parton model, and any clean jets that may have been hiding in the data were swamped by the azimuthally uniform background.

Implications. The high-multiplicity and high-E_T surprises presented by these first p̄p collider data appear to have significant practical as well as theoretical implications. With regard to the theory of hadronic collisions, the unexpectedly broad fluctuations in both multiplicity and total transverse energy seem to imply long-range correlations between particles produced far apart in phase space. In the more limited phase space available in lower-energy experiments, only local phase-space correlations had been clearly observed in multiparticle production.

Clean parton-model jets, it would appear, will be much more elusive in hadron–hadron scattering than in e^+e^- collisions. Geoffrey Fox (Caltech) presented a QCD-theoretical analysis at Madison indicating that both the prolific azimuthally-uniform high-E_T events and the apparently much rarer clean jets are consistent with QCD, *if* one takes adequate account of "gluon bremsstrahlung," the radiation of gluons by quarks when they experience high-momentum-transfer collisions. Fox emphasizes that the clean jets are still there with the proper rate and properties predicted by QCD; they are simply harder to see than one would naively have expected, given the overwhelming gluon-bremsstrahlung background.

The practical implications of the high-E^T and high-multiplicity events concern primarily the search for the intermediate vector bosons, which is, after all, the main impetus for the current race to higher energies. Because the cross sections for production of the $W^\pm$ and the Z^0 are expected to be exceedingly small, one must devise a trigger to weed out the overwhelming majority of "uninteresting" events in a hadron–hadron collider. The charged W's can decay into hadrons or, less frequently, into lepton pairs. Because it is generally considered a hopeless task to find hadronically decaying W's, one looks for a very high-E_T single electron or muon as a signature of the leptonic decay of the 80-GeV boson. The simplest scheme that is being considered for the SPS collider and the Tevatron is just to trigger on high total E_T in the electromagnetic calorimeters. The lesson from the first p̄p collider data is that such a trigger would bring along an overwhelming hadronic background. One will need, Fox suggests, a highly segmented calorimeter system that can ferret out very localized high E_T. He also warns that because vector bosons are produced in particularly violent quark–quark collisions they will be accompanied by lots of gluon bremsstrahlung.

The high-multiplicity events one must now expect at ultra-high-energy hadron colliders will require very elaborate systems of on-line data collection. Recording the data from a single event of *ordinary* multiplicity at the UA1 detector takes thirty thousand 16-bit words. "The first thing that happened when the UA1 energy trigger was turned on, was that 25% of the events overflowed the buffers," Cline told us. Things will get even more difficult when the luminosity is increased, he suggests. —BMS

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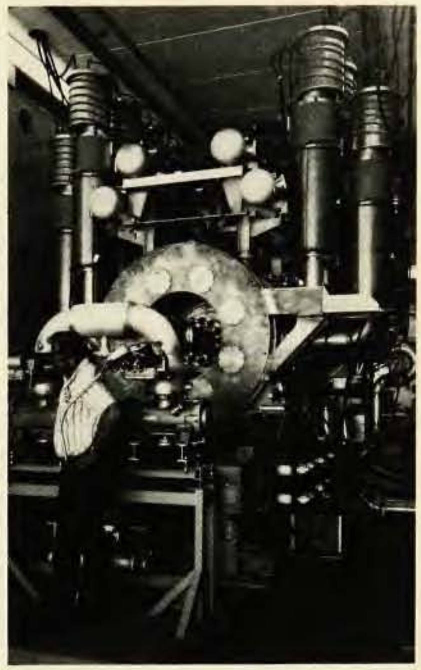
ATA: 10-kA pulses of 50-MeV electrons

Assembly of the Advanced Technology Accelerator (ATA) began in December at an isolated site 15 miles southeast of the Lawrence Livermore Laboratory. When it is completed in October (the project appears to be on schedule), the 256-foot linear induction accelerator is expected to generate repeated 10-kiloamp pulses of 50-MeV electrons—an order of magnitude higher energy than any previous induction linac capable of high current and high repetition rates.

The great majority of linear accelerators in operation today are radio-frequency, traveling-wave devices. Although such linacs can accelerate electrons to tens of *billions* of electron volts, they are severely limited in current capability. The electromagnetic field generated by the beam itself couples back into the resonant waveguide structure that provides the voltage amplification in an rf linac, generating beam-breakup instabilities when a modest current limit is exceeded. The two-mile-long Stanford Linear Accelerator, for example, is limited to electron currents of less than a hundred milliamps by such instabilities. Furthermore, the multi-gigawatt instantaneous power levels required for a high-current, high-energy linac are beyond the capacity of present rf power sources.

For the high-energy physics uses to which the SLAC accelerator is put, one is not interested in multi-kiloamp currents—only very high individual particle energies. But there are applications for which one wants extremely intense beam currents, delivering repeated multi-kilojoule or even megajoule pulses of charged particles. Although the Defense Department's primary objective in funding the ATA is to produce an experimental facility for the study of charged-particle beam propagation in air, to examine the feasibility of particle-beam weapons, such induction linacs are also of considerable non-military interest. The ATA could serve as a unique beam source for free-electron lasers. Historically, the world's first induction linac, the Astron I accelerator, was built at Livermore in 1963 by Nicholas Christofilos, to provide the high electron-beam currents required by his Astron magnetic-confinement scheme for fusion plasmas. Induction linacs are also of interest for inertial-confinement fusion with intense heavy-ion beams.

Ferromagnetic induction linacs. In contrast to an rf linac, where the electrons effectively ride an electromagnetic wave down a series of resonating cavities, in an induction linac the particles pass through an array of non-resonant cavities, each of which presents the particle with a quasi-electrostatic accelerating gap fed by a high-voltage pulse from a transmission line. One can contrive the topology of the transmission line at the gap so that the electron sees at first only the accelerating voltage across the coaxial line, and not the decelerating voltage that invariably accompanies it. But the transmission line must terminate somewhere, completing the circuit lest the energy it transports radiate away out an open end. Such a termination will produce a reflected voltage pulse of opposite polarity. If the beam passes



Underground tunnel near Livermore for the Advanced Technology Accelerator and adjoining experimental tank is 200 meters long. When completed this Fall, the 190 ferromagnetically loaded modules of this induction linac should produce repeated 10-kiloamp pulses of 50-MeV electrons, primarily for the study of charged-particle-beam propagation in air. The Experimental Test Accelerator, the 3-year-old, 2.5-MeV prototype for the ATA, is seen at right.

through the accelerating gap before the reflected voltage pulses can decelerate it, the problem is solved. But this is practical only for a beam bunched into extremely short pulses, on the order of 10 nanoseconds.

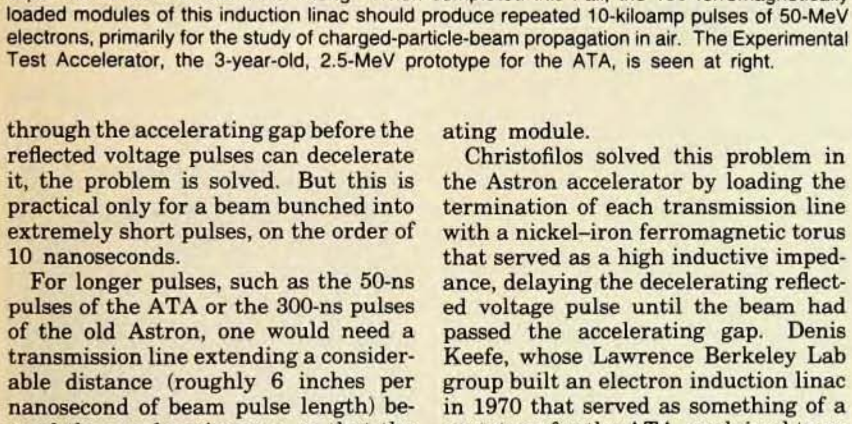
For longer pulses, such as the 50-ns pulses of the ATA or the 300-ns pulses of the old Astron, one would need a transmission line extending a considerable distance (roughly 6 inches per nanosecond of beam pulse length) beyond the accelerating gap, so that the voltage pulse reflected back from the termination at about the speed of light would not return to the gap before the beam pulse had passed. This would make for an impractically long accelerating module.

Christofilos solved this problem in the Astron accelerator by loading the termination of each transmission line with a nickel–iron ferromagnetic torus that served as a high inductive impedance, delaying the decelerating reflected voltage pulse until the beam had passed the accelerating gap. Denis Keefe, whose Lawrence Berkeley Lab group built an electron induction linac in 1970 that served as something of a prototype for the ATA, explained to us that this ferromagnetic loading is effectively the same as reducing the velocity of light in a medium by increasing its permeability.

The ATA group at Livermore, led by Richard Briggs, uses ferrite rather than nickel–iron as the ferromagnetic loading, because this non-conducting material has lower eddy-current losses. "But if we were designing the ATA today," he told us, "we'd probably use Metglas," a recently developed high-resistivity metallic glass with much higher saturation magnetization than ferrite.

The main accelerator consists of a sequence of 190 accelerating modules, each of which adds 250 keV of kinetic energy to electrons that originally come from the injector at 2.5 MeV. The accelerating gap in each module is fed by two transmission lines, introducing 250-kilovolt pulses of 50-ns duration at opposite sides of the cavity. One side of each line opens into the accelerating cavity, producing the quasi-electrostatic fringe field seen by an electron as it passes in a time much shorter than the 50-ns voltage "flat top." The two short circuits that carry the return currents of the two transmission lines are linked by a ferrite torus, through which the beam passes (see illustration).

One can think of each accelerating module as a one-to-one, single-turn transformer, we were told by William Barletta of the ATA group. The transmission line is the primary loop, and the electron beam serves as the secondary, picking up the full 250 kilovolts. The ferrite torus is of course the transformer core. As the transmission-line current flows around it, the magnetization of the ferrite is driven from its initial saturation in one direction to saturation in the opposite direction. The accelerating voltage is maintained at a constant 250 kV across the gap for the duration of the 50 nanoseconds it



Three of the ATA's 190 accelerating modules. In each cavity, the electrons gain 250 keV from a quasi-electrostatic fringe field supplied by the transmission lines (central conductors black) in 50-nanosecond pulses. Inductive loading in each module is supplied by a ferrite torus (dark color) linking the terminations of the two transmission lines. One can think of the ferrite as the core of a one-to-one transformer, linking the primary (transmission lines) with the secondary (the electron beam). The reversal of the core's magnetization maintains the accelerating voltage across each cavity for 50 nanoseconds, the beam-pulse duration.

takes to drive the magnetization to the opposite saturation.

This is the inductive loading that keeps the reflected decelerating voltage at bay. The product of the accelerating voltage and its duration is given by the product of twice the saturation magnetization (the "flux swing") and the cross-sectional area of the ferromagnetic core. Although the beam sees only an electrostatic field during its brief transit through each gap, it is effectively the time-varying magnetic flux in the ferrite core that maintains the accelerating voltage. Hence the name induction linac.

High repetition rate. Non-ferromagnetic "air-core" linacs built in the Soviet Union and at Sandia have produced even higher electron-beam currents than the ATA. But in the absence of ferromagnetic loading they are restricted to beam pulses not much longer than 10 ns. (The Soviet linac has recently achieved significantly longer pulses by the use of water as a dielectric to increase the capacitance of its accelerating cavity.) The enormous power levels of such short-pulse accelerators, Keefe told us, present technological problems that have until now prevented sustained operation at high repetition rates. They have been basically "single-shot devices," he told us. The ATA, by contrast, is designed to operate for long periods at a steady 5 pulses per second. In its alternative "burst mode," the accelerator can also operate at kilohertz rate for 10-pulse bursts, each followed by a 2-second respite.

The unique importance of the ATA for accelerator technology, Keefe emphasizes, lies in the achievement of these sustained repetition rates in a high-current, high-energy machine. The ETA (experimental test accelerator), the ATA's immediate predecessor at Livermore, was able to achieve similarly high current and repetition rate in 1979, but this prototype only accelerated electrons to 5 MeV. The second generation Astron accelerator, completed a few years before Christofilos's untimely death in 1972, reached an 850-amp current of 6-MeV electrons, but in a much longer structure than the ETA. It achieved impressive repetition rates up to 30 pulses/sec.

An important function of the ETA and ATA, Briggs explained, "is to teach us how to build these pulsed power modules so that they can run all day without failing or wearing out." Running at several million pulses per year for nearly three years, the ETA has yielded much information about component lifetimes. "With the very high voltage and power levels in each module, the machine has found lots of ways to tear itself apart," he told us.

The 50-nanosecond, 250-kV pulse for each accelerating module is formed by a Blumlein line (the corruption "Blumline" is inevitable). These special pulse-contracting coaxial lines have a third annular element between the inner and outer coaxial conductors that effectively serves as a capacitor plate as it is "slowly" charged up to 250 kV over 10 microseconds. At this point a spark gap is fired, discharging the third element to the outer conductor and sending a 250-kV pulse, now contracted to 50 ns, down the line. Thus the Blumlein, which feeds the transmission line to the accelerator, amplifies the power of the original 10-microsec pulse by a factor of 200.

The Blumlein spark gaps suffer a lot of wear and tear, Briggs told us. The ATA group is therefore pursuing the development of Metglas magnetic switching devices to replace the spark-gap switches in the pulse-forming networks of future induction linacs. Very few induction linacs have been built to date. "People have tended to use rf accelerators even for applications better suited to induction linacs," Briggs explained, "because induction linacs are a much less familiar technology. As we prove it out, they'll find many new applications where it will replace rf machines."

Applications. The experimental area into which the ATA fires its 10-kiloamp pulses of 50-MeV electrons will be used primarily to study beam propagation in air. In vacuum, the mutual coulomb repulsion of a charged-particle beam always wins out over the self-pinching magnetic attraction, breaking up the beam in the absence of an external focusing field. On the other hand, when a charged-particle beam traverses a gaseous medium such as air, the resulting ionization can play a focusing role. The ATA group will study the physics of this phenomenon, investigating the feasibility of propagating high-current, high-energy electron beams through air. The ATA is also eminently well suited, Briggs told us, to serve as an injector for high-energy free-electron-laser experiments.

The Berkeley induction electron linac was built ten years ago to investigate the suggestion of V. I. Veksler (Dubna) that protons could be accelerated cheaply to very high energies by imbedding them in "smoke rings" of electrons. When it became clear this scheme would not be suitable for accelerating protons to extremely high energies, the Berkeley project was terminated in 1975. But Keefe told us that the Soviets have recently reported remarkable success in applying Veksler's idea to the acceleration of heavy ions. The Berkeley group is currently working on the direct acceleration of heavy ions in a linear induction accelerator, primarily for inertial-confinement fusion. Electron beams from induction linacs are being considered as a means of heating the plasma in magnetic-confinement fusion devices, either directly or through the generation of intense microwave (or mm-wave) radiation.

Flash radiography is another potential application of the ATA. The electron beam could generate intense short x-ray pulses that would serve for high-time-resolution x-ray photography of rapidly varying dense materials. This technique is useful for the investigation of weapons implosion and for the study of equations of state in solids. Flash radiography has been used, for example, to look for the metallization of quartz and hydrogen at ultra-high pressures.

The ATA facility has been dedicated to the memory of Christofilos. Leaving aside its many contributions to magnetic-confinement fusion, Christofilos's Astron project was seminal for the development of induction-linac technology. —BMS

National Submicron Facility

The National Research and Resource Facility for Submicron Structures was dedicated at Cornell University in mid-October. Although the facility was established at Cornell in 1977 with a $5-million grant from NSF, it has only recently moved to a new building, named for Lester Knight.

Shown in the photograph above are Lester Eastman and Colin Wood operating a molecular beam epitaxy system.

The facility is directed by Edward D. Wolf. (He described the capabilities of the submicron structure facility in PHYSICS TODAY, November 1979, page 34.)