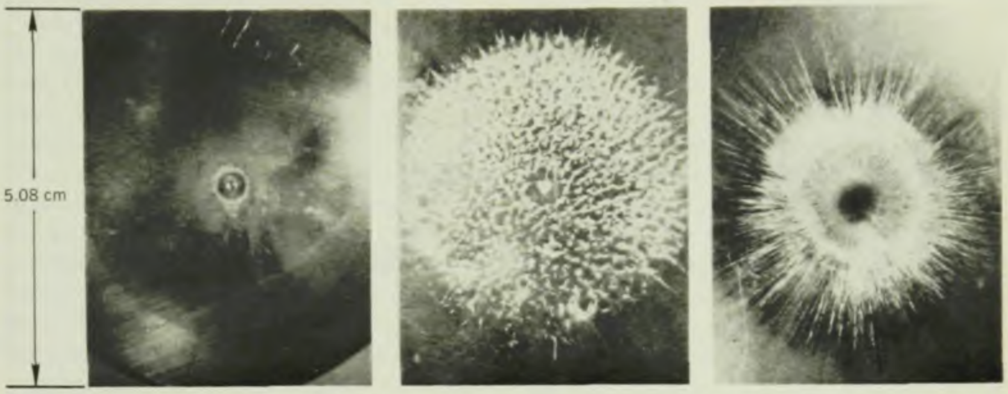
search & discovery

Many laboratories try for fusion with electron beams

For nearly a decade several laboratories in the US—the Naval Research Laboratory, Sandia Laboratories and Physics International among others—have been experimenting with intense relativistic electron beams. More recently interest in laser fusion also has stimulated interest in electron-beam fusion, and the pace quickened with several more laboratories joining the fray—Cornell University, Lawrence Livermore Laboratories, Air Force Weapons Research Laboratory, North Carolina State University, Maxwell Laboratories in San Diego, as well as laboratories in the Soviet Union.



Target damage from Sandia intense relativistic electron beam. At left is the very slight anode damage from a current-carrying wire alone. In middle photo a 5.08-cm-diameter cathode with a 0.31-cm anode–cathode gap were used. The current from this cathode alone is insufficient to allow self-pinching. At right is photo made with an exploding-wire current-carrying plasma inserted into a depression in the cathode. The radial spray of molten aluminum is seen to emanate from a deep, 1-mm-diameter crater located on the axis.

Much progress has been made in understanding of electron-beam formation, equilibrium and stability. For example it is now understood why an electron beam can propagate in seeming violation of the so-called Lawson–Alfvén criterion, which states that there should be no propagation when the self-magnetic field of the beam becomes so intense that the Larmor radius of the beam electrons equals the radius of the beam. But many problems and mysteries remain. Probably the foremost among them is how to focus the electron beam to achieve energy densities suitable for electron-beam-induced fusion (and competitive with those available from lasers) while providing a means for coupling the beam efficiently into the target. Mechanisms for coupling include use of low kinetic-energy beams (less than about 1 MeV), excitation of instabilities, and self-magnetic effects.

Some observers believe electron beams are more promising than lasers. Either the electron beam or the photon beam can be used to heat a pellet of deuterium or deuterium–tritium to thermonuclear temperatures but the basic absorption mechanisms are profoundly different.

Work with both types of beams borders on the classified as soon as one talks about the beam interacting with the target. But over the past year declassification has revealed that the laser-energy requirement could be reduced by many orders magnitude if the pellet were imploded to very high densities (PHYSICS TODAY, August 1972, page 17). Although it is much easier to focus photons than electrons, the electron-beam machines are further along in available total energy, according to Norman Rostoker (University of California, Irvine and Maxwell Laboratories). On the other hand much of the power is wasted with present electron beams because most of the nuclear reactions would occur in a couple of nanoseconds and their pulses last tens of nanoseconds whereas some laser pulses are in the nanosecond range or shorter, he noted. Shorter pulse machines are under development at Maxwell Laboratories under Alan Kolb.

A variety of approaches for heating the pellet have been discussed[1] by Friedwardt Winterberg (University of Nevada). Franklin Ford (Physics International) suggested electron-beam initiation of deuterium–tritium pellets with short-pulse, high-current electron beams in 1965. Research at Physics International has been directed at attaining the required parameters of current density, short pulse duration and energy deposition. Some groups are

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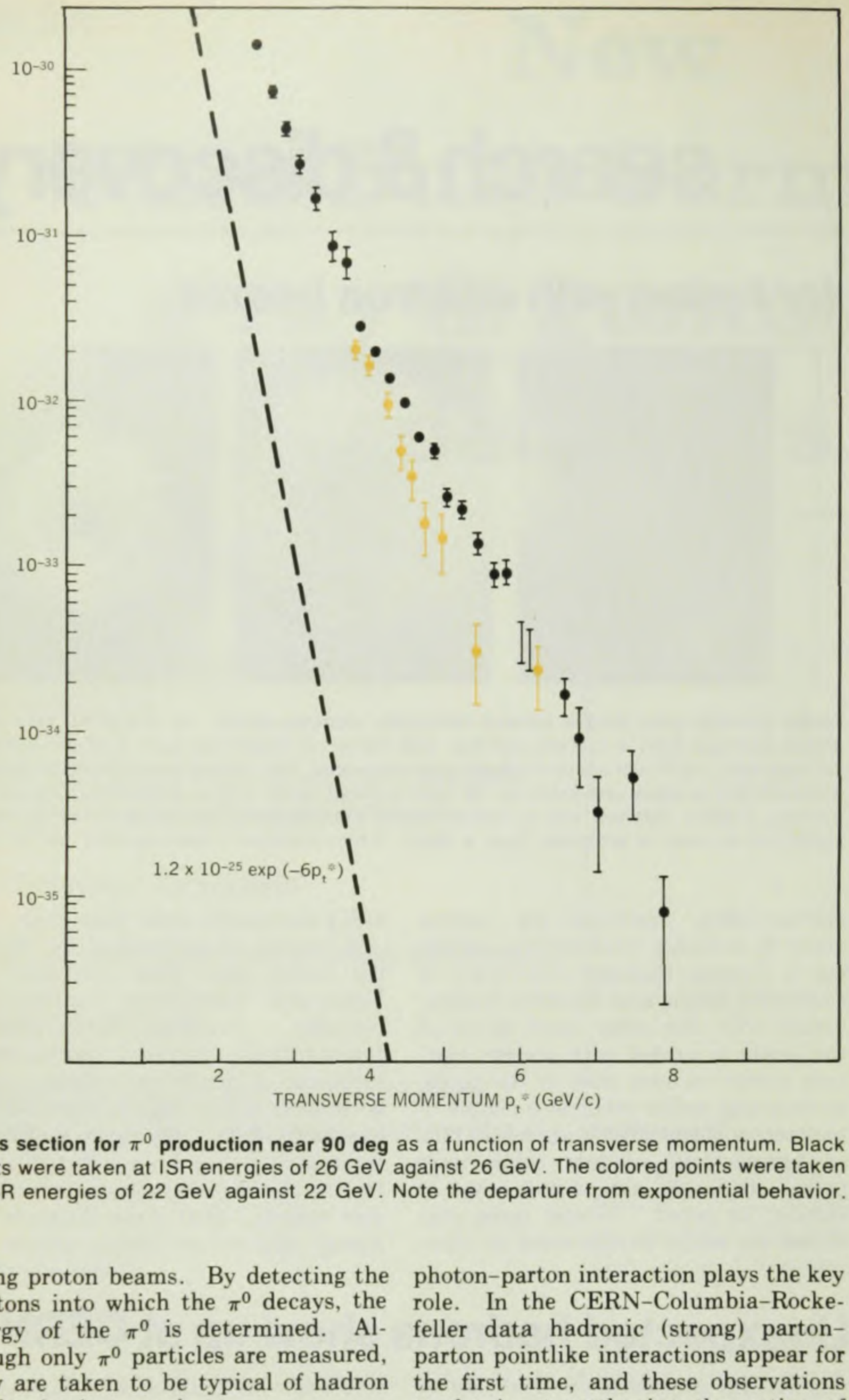
Unexpected hadrons show up at CERN

High-energy physicists are intrigued by some new results produced at the CERN Intersecting Storage Rings. At the New York American Physical Society meeting on 1 February, Luigi di Lella reported on experiments that showed an unexpectedly large amount of hadron production at high transverse momentum. The experiments were done by a CERN–Columbia–Rockefeller collaboration.

(The group consists of B. J. Blumenfeld, F. W. Busser, L. Camilleri, Rodney L. Cool, Luigi di Lella, G. Gladding, Leon M. Lederman, L. Litt, A. Placci, B. G. Pope, S. L. Segler, A. M. Smith, J. K. Yoh and E. Zavattini.)

In thinking reminiscent of the old saying, "There's no reason for it; it's just our policy," many people believed that in proton–proton collisions one would not see hadrons with high transverse momentum. All the experimental evidence indicated that hadron production dropped off in a steep exponential fashion with increasing transverse momentum up to 1 or 2 GeV/c. And a Brookhaven experiment at 3 GeV/c still showed the exponential behavior; it involved proton–proton collisions to produce muon pairs. The new ISR data goes up to 9 GeV/c and it shows, starting at between 1 and 2 GeV/c, an excess over the exponential behavior by many decades, suggesting a power law.

The experimenters looked at the inclusive reaction $p + p \rightarrow \pi^0 +$ anything. Identical spectrometers, consisting of hodoscopes, spark chambers and lead-glass Cerenkov counters were placed at 90 deg on opposite sides of the two col-



Cross section for π^0 production near 90 deg as a function of transverse momentum. Black points were taken at ISR energies of 26 GeV against 26 GeV. The colored points were taken at ISR energies of 22 GeV against 22 GeV. Note the departure from exponential behavior.

liding proton beams. By detecting the photons into which the π^0 decays, the energy of the π^0 is determined. Although only π^0 particles are measured, they are taken to be typical of hadron production in general.

Another feature of the ISR experiment is that for fixed transverse momentum the cross section increases with energy. Various theorists are trying to explain this fact plus the power-law dependence for hadron production as a function of transverse momentum. Among the theorists who have done this are: James D. Bjorken, Stanley Brodsky and J. Kogut of SLAC (who anticipated the possibility of a break in the hadronic steep exponential), G. F. Gunion, Brodsky and R. Blankenbecler at SLAC, P. V. Landshoff and G. C. Polkinghorne at Cambridge University.

All of these theories apply the parton model, which is successful in explaining the deep inelastic electron–proton scattering at SLAC. In these experiments a photon–parton interaction plays the key role. In the CERN-Columbia-Rockefeller data hadronic (strong) parton–parton pointlike interactions appear for the first time, and these observations go far in strengthening the notion of pointlike constituents in the proton, Lederman says. Another interpretation of large transverse momentum based on a multiperipheral model has been given by D. Amati, L. Caneschi and M. Testa at CERN.

Still another feature of the ISR experiment was to look for the production of the intermediate-vector boson, W, which would be signaled by the production of single electrons at high transverse momentum (which would be produced by the decay of the W into an electron and neutrino). The ISR experimenters used the earlier Brookhaven muon-pair experiment as a calibration point, because if the conserved vector current hypothesis is correct, the Feynman diagram for the emission of a virtual photon to make a muon pair is closely related to the emission of a W to make an electron–neutrino pair. Lederman told us that for a large range of plausible models for how the W is made, their apparatus would yield a peak of electrons at half the mass of the W. They find an upper limit for electron yield that dies away at about 5 GeV/c transverse momentum.

A number of theorists, such as Sidney Drell (SLAC) and T.-M. Yan (Cornell), using the parton model, have shown that the muon-pair experiment may be scaled to higher energies. Lederman, on the basis of his experiment, says that scaling could still be right but just barely. In a plot of electron-pair production as a function of the mass of the pair, scaling predictions go near the upper ends of the experimental points, which themselves are upper limits. If scaling and the other hypotheses turn out to be correct, Lederman says, then the W would have to have a mass greater than 25 GeV; thus it could be produced only with great difficulty at the energies available at the National Accelerator Laboratory. —GBL

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considering inertial confinement of the pellet, surrounding it with a high-Z material that will extend the confinement time. Another possibility is that the self-magnetic field of the focused electron beam will help to confine the plasma, keeping the charged fusion products within a small volume. Still another possibility is that "anomalous stopping" of the electron beam will occur, that is, the electrons will have a much shorter range than one might expect from simple theory.

Typical laser schemes employ multiple beams that surround the target, at least in part because it is too difficult to build a single laser that is energetic enough. Rostoker told us that only one beam is really necessary for implosion because the thermal conductivity of the target electrons is high enough that the geometry becomes spherical pretty quickly.

Another possibility for a two-dimensional delivery scheme is to use a ring-shaped cathode with a large number of radially arranged fine wires that explode, according to David Mosher of the Naval Research Laboratory. Gerald Cooperstein (NRL), and William Link, Donald G. Pellinen and Sidney Putnam (Physics International), and Ken Prestwich (Sandia) have demonstrated that intense beams of electrons can be turned around corners in conducting guide pipes or that several beams can be delivered independently to the same place.