On the Trail of Elemental Matter

Experiments now being analyzed seek a quark-gluon plasma, matter stripped to its most elementary constituents

By DIETRICK E. THOMSEN

Most physicists now believe that quarks are elementary constituents of matter, the basic elements out of which everything is built. One of the experimental attempts to study quarks concentrates on reducing matter to a state in which only quarks and the particles called gluons, which embody the forces that quarks exert on each other, are present, a so-called quark-gluon plasma. This would be matter in an elemental state, stripped of all the phenomena and attributes that arise from combination and structure into protons, neutrons, atomic nuclei, atoms and more complicated structures up the scale.

Can experiment produce such a state of matter, in which neither atoms nor nuclei nor protons nor neutrons are present, but only quarks and gluons? Researchers may be on the verge of demonstrating it. A complex of experiments in search of a quark-gluon plasma, set up at the CERN laboratory in Geneva, Switzerland, by half a dozen groups composed of hundreds of physicists from dozens of institutions in Asia, Europe and North America, had its first run last fall, and will have another next fall (SN: 5/24/86, p.331). The first results of the first run have just been published, and the preliminary indications look favorable, but there is still a lot to analyze.

"Certainly no quark-gluon plasma fell out of the data," says Lee Schroeder of the Lawrence Berkeley (Calif.) Laboratory (LBL). "It's going to be a long, concentrated effort in digging out everything that's going on."

The experiment used the CERN Super Proton Synchrotron (SPS) to accelerate ions of oxygen to two different energies, 60 billion electron-volts (60 GeV) for each neutron and proton in the oxygen nucleus and 200 GeV per neutron and proton, and struck them against standing targets of lead. The analysis concerns what happened in these high-energy collisions of oxygen and lead nuclei. The SPS heretofore has been one of the world's foremost proton accelerators; it was somewhat modified for the acceleration of ions. In its previous particle physics experiments, the SPS was studying the behavior of quarks on a more or less individualistic basis; this experiment is looking for a large collective state, a quark-gluon plasma formed in the nuclear collision.

A preliminary run in September 1986 was intended only to test the hardware, but it went so well that some of the experiments, particularly the streamer chamber belonging to the "NA35 Collaboration" (59 physicists from 14 institutions in eight countries), were able to take data. It is NA35's first results that have just been published under the names of A. Bamberger of the University of Freiburg, West Germany, et al. in PHYSICS LETTERS B. The first formal run, in which all groups got data, lasted from Nov. 17 through Dec. 8.

"My first impression as an outsider is that it was remarkably smooth, and everybody is well pleased," says Schroeder.

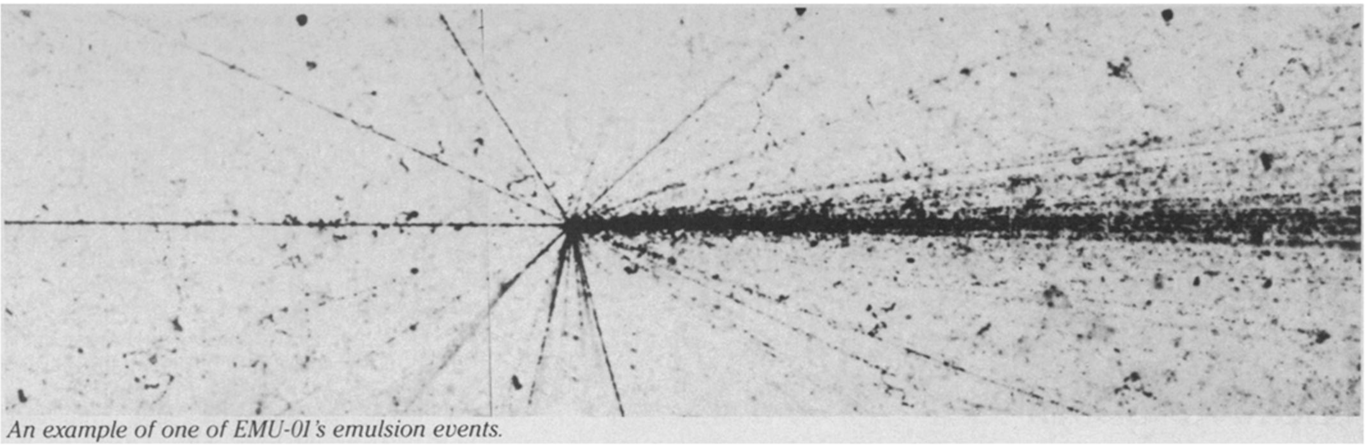
One who was there, Hans-Georg Ritter of LBL, says, "The accelerator worked so well. All groups are working hard, reading through basic first results, counting multiplicity and measuring transverse energy."

The multiplicity of new particles created in the nuclear collision, and the energy they carry off in directions transverse to the beam of accelerated oxygen, are two early criteria for determining that the experiment is going in the right direction, and these indications are so far good, according to NA35's publication.

"Originally all the motion is in longitudinal energy, and then in the reaction it gets some sidewise kick," says Ritter, "and the larger this transverse energy, the more violent the reaction."

"You're able to take all that longitudinal energy and make it interact enough so that it's kicking things out in all directions . . . ," says Schroeder. "The name of the game for making the plasma is to try to get the energy density up, and this kind of transverse motion is one thing that


Photos: LBL
Streamer chamber data from the "NA35 Collaboration."


An example of one of EMU-01's emulsion events.

suggests you are starting to get the energy density up."

The multiplicity of tracks in the NA35 streamer chamber pictures is quite large by the usual particle-physics standards, and the quality is different from previous nuclear collisions, as Schroeder indicates, comparing an NA35 image with one of a collision at much lower energy in LBL's Bevalac accelerator. The outcoming tracks in the Bevalac picture are dominated by postively charged particles, mostly protons from the projectile nucleus that have gone through the target. The NA35 events have a mixture of positive and negative particles, between 250 and 400 charged particles plus neutral particles the streamer chamber doesn't see.

"The yield is not dominated by original neutrons and protons," says Schroeder, "but by new particles created in the collision"—another indication that something fundamental is happening there.

In the images the experimenters search for specific things that theorists have said will indicate the presence of quark-gluon plasma, and there is talk that some of these are being found, but no one wants to go on the record yet. One such item being sought by the analysis at LBL is production of pairs of lambda particles. In the streamer chamber pictures, the indication of lambda particles is a "vee," a vertex from which two tracks curve away in opposite directions. Skilled technicians called scanners search for the vees.

The scanners sit in a half-darkened room over light tables on which the films from the streamer chamber cameras are projected frame by frame. When scanners find a vee, they position a computer "mouse" over it and punch a code, and the vee's location is recorded in a computer memory.

These events are very difficult to measure, says physicist Grazyna Odyniec of LBL, who was supervising the scanners when SCIENCE NEWS visited them. To do a global analysis of an image takes a scanner a day. Three images of each event must be measured for a three-dimensional reconstruction, and there are 50,000 events. Four laboratories are dividing the work.

Scanners do multiplicity counts, but rather than wait for them, this experiment carries an auxiliary device that gets quick multiplicity counts (10 to 15 percent accurate, according to Schroeder) and track-density profiles, and can look for vees. It is a charge-coupled device (CCD) camera developed by John Harris of LBL.

A CCD is an array of photoelectric elements that delivers a digitized image directly to a computer memory. The information it gives can be used to trigger calorimeters that measure transverse energy so that they measure only events with a large multiplicity. Right now the CCD camera is an auxiliary because it is not fast enough to image every event online, but in the future Harris and his associates hope to make it a more primary instrument.

Another experiment being analyzed at LBL is EMU-01, a collaboration of a dozen or so laboratories in nine countries, which uses nuclear emulsions as a recording device. Nuclear emulsion is the same as photographic emulsion, and the particles make dark tracks in it. Traditionally it comes in large blocks, and the nuclear collision takes place in the block. After the event, the emulsion is analyzed with special binocular microscopes.

The day we visited, physicists Harry Heckman of LBL, Barbara Judek of the Canadian National Research Council in Ottawa, Ontario, and technician Santa Chatterji of LBL were working the microscopes.

EMU-01 also uses a newer method, which consists of spreading the emulsion on thin plastic sheets and then stacking the plates with known distances between them. The blocks give a side view of an event, as the streamer chamber does, but the stacks, which were designed specifically to resolve tracks that are close together, give a head-on view. Dialing the microscope to focus on successive plates up and down the stack, one sees the spray of particles coming at one's face like spears in a 3-D movie—as Heckman puts it, "right into your eyeball."

The emulsion cannot distinguish positive charge from negative, but it sees the neutral particles, and it is better than anything else at resolving one track from another. Yasha Karant of LBL, another physicist involved, points out that, at these high energies, tracks are very straight, and two that originate at the same point diverge very slowly. Karant says the emulsions can measure angles as narrow as 1/100,000 of a radian, equivalent to a separation of only 3.5 centimeters in a kilometer.

"The streamer chamber got the jump," says Heckman. "We're still calibrating, scanning, locating events, selecting events." Early in April the participants in EMU-01 expect to meet to discuss what they have.

Many of the participants in this first run expect to report their results at a meeting in West Germany in August. Meanwhile, the success so far has prompted some physicists to propose turning the SPS into a dedicated accelerator of heavy ions. CERN is building a new accelerator, LEP, and when LEP is complete, the particle physics interest will shift there. The SPS will be an injector for LEP, but it will have plenty of time for heavy-ion work. CERN is owned by 14 European governments, and Ritter says that several of them, including particularly Sweden and West Germany, are interested in a separately funded heavy-ion program with the SPS. □