Pion-Proton Scattering Verifies Forward Dispersion Relations

A year-long on-line computer experiment at the Brookhaven AGS has verified the dispersion relations for forward elastic scattering at energies as high as 29 GeV. The experiment, done by S. J. Lindenbaum, Satoshi Ozaki, Kenneth J. Foley, Roger S. Jones, William A. Love, Edward Platmer, C. A. Quarles and Erich Willen, measured the π^+–p and π^-–p elastic scattering cross sections from 8 to 26 GeV at 1 to 30 milliradians. (Results were reported at the Coral Gables Conference on Symmetry Principles at High Energies late in January and at the New York APS meeting.) The experiment, according to Lindenbaum, gives one a quantitative crystal ball that looks all the way to infinity.

The good agreement between experiment and theory, Lindenbaum says, shows that microscopic causality is correct for energies at least as high as 29 GeV. Since causality does hold at these energies, Lindenbaum concludes that if there is a fundamental length, it is less than 10^{-15} cm (and probably less than 10^{-16} cm). Thus over these distances signals do not travel faster than light, and one should not expect that scattering will occur before a particle hits its target.

Dispersion relations were first developed for light dispersion in an absorbing medium; the index of refraction is expressed as a complex quantity whose real part corresponds to the scattering and whose imaginary part to the absorption.

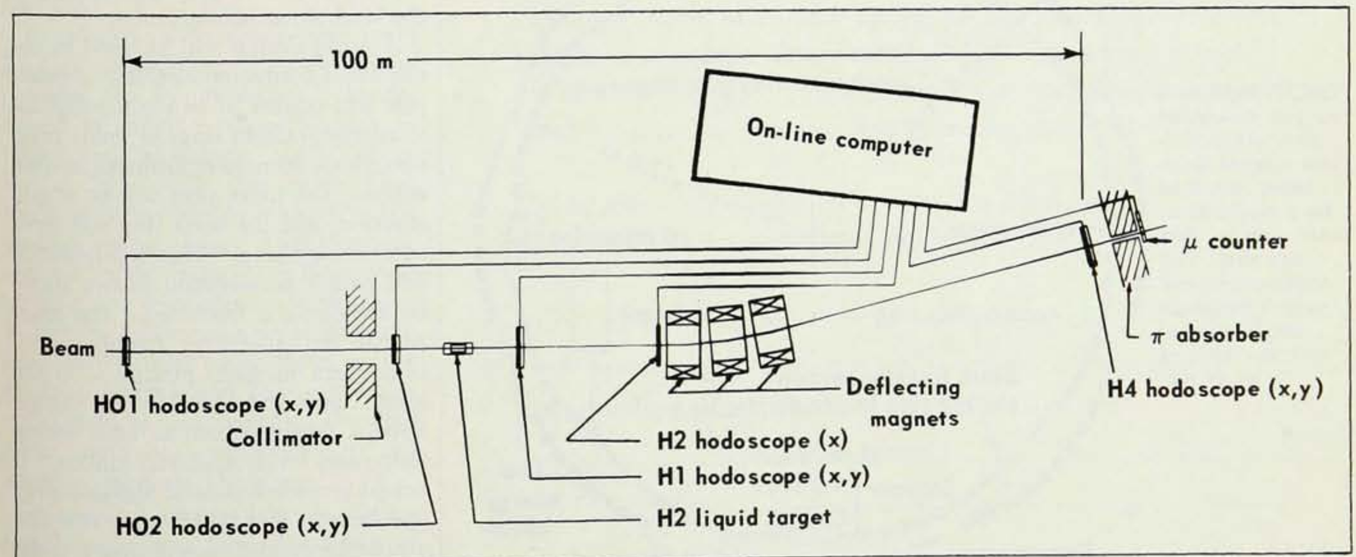
When dispersion relations are extended to particle scattering, the equations become extremely involved unless one considers only forward scattering. Then one can check the theory experimentally, most easily for pion-proton scattering, for which the equations reduce to only one complex amplitude. Proton-proton scattering is trickier; because of the proton spin there are three complex functions to determine.

In the forward dispersion relations the real part of the amplitude is approximately proportional to the integral over energy from 0 to $+\infty$ involving the total cross section. By plugging in measured values of total cross section at different energies up to the highest, and using extrapolations beyond, the integral can be evaluated. The Lindenbaum group uses the relations to predict the real part of the nuclear scattering amplitude and then compares this prediction with the experimentally determined real part.

In the experiment one can find the square of the scattering amplitude from the differential cross section and the imaginary part from the total nuclear cross section. But the observed real part of the scattering is the sum of the nuclear and Coulomb scattering, whereas one is looking for the nuclear scattering only. The experiment has greatest sensitivity when the Coulomb amplitude is equal to the nuclear amplitude. (This region corresponds to distances large enough that the measured scattering amplitude is the same as the forward scattering amplitude.) For π^+ scattering the experiment revealed constructive interference and for π^-, destructive interference. The known Coulomb effect can be subtracted out.

Near 100 MeV, the interference between Coulomb and nuclear scattering occurs at about 10 deg. But at, say 14 GeV, the whole effect occurs between 2 and 10 milliradians. So to observe the interference, Lindenbaum had to do his experiment at many closely spaced angles from 1–30 mrad.

The experiment, which ran for 1200 hours on the AGS, is the third in a series of pioneering on-line computer ex-



SMALL-ANGLE SCATTERING APPARATUS. More than 10^{12} counter combinations are possible.

periments run by Lindenbaum and his collaborators. In the new experiment as many as 2–6 million trigger-selected scattered events per hour occurred. A PDP-6 was used on-line, while the experiment was running, to calculate 10–20% of the events. Meanwhile the data was also continuously processed off-line by using the computer's time-sharing feature. For each event the computer reconstructs the particle path and rejects those events that did not come from the target. By the end of the experiment there were data on about 30 million events at each momentum, with a total of several billion events.

A conventional scattering experiment has one counter telescope in the incident beam, one in the scattered beam and then one beyond the deflecting magnet (to ensure that elastic scattering has occurred). For each angle one must then pick up and move the counters, with consequent risks of misalignment.

The Lindenbaum experiment, on the other hand, measures all angles of interest simultaneously, by replacing each counter telescope by a scintillation-counter hodoscope. Actually five hodoscopes are used in the arrangement shown in the figure on page 63.

Each hodoscope has an array of long thin detectors to determine the x coördinate of a particle and an intersecting array of similar detectors to determine the y coördinate. The last and largest of the hodoscopes has 120 x elements and 24 y elements. The total number of different counter combinations is more than 10^{12}.

An intense beam of pions (10^4–10^5 particles per 2-sec pulse) is selected by Cerenkov counters; pion position is located within 1.5 mm and about 0.1 mrad. The pions are then scattered by a liquid-hydrogen target, and their angles are measured by a hodoscope. Then the pions pass through deflecting magnets, and their momenta are measured. Overall momentum resolution is about 0.4%, and overall angular relation is about 0.4 mrad.

The experiment, besides measuring elastic and total cross sections for π^+–p and π^-–p, did the same for p–p. The latter results, however, could not easily be used to check the forward dispersion relations.

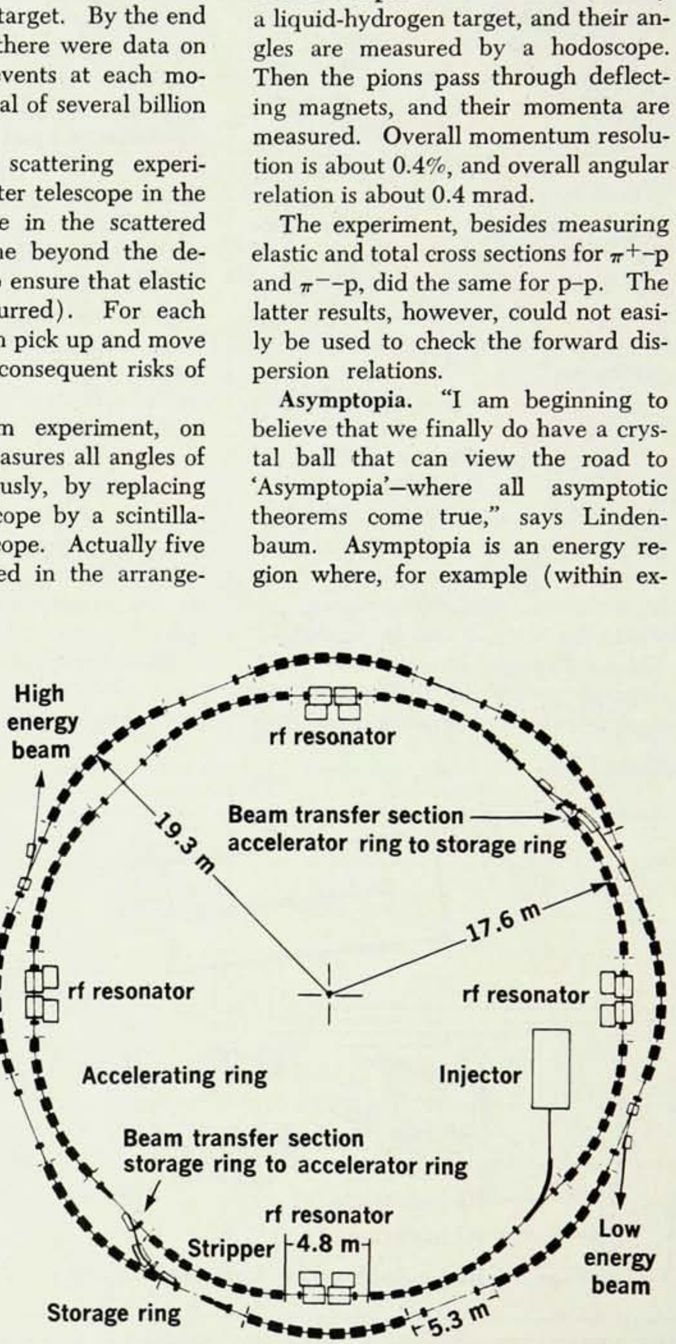
Asymptopia. "I am beginning to believe that we finally do have a crystal ball that can view the road to 'Asymptopia'—where all asymptotic theorems come true," says Lindenbaum. Asymptopia is an energy region where, for example (within experimental precision, say 0.1%), total nuclear cross sections for π^+–p and π^-–p would be equal (at 29 GeV they are different by about 5%); so would those for $\bar{p}$–p and p–p and those for K^+–p and K^-–p.

Ideas of where the asymptotic region begins have changed as accelerator energies increased. As Lindenbaum notes, "Asymptopia is like an oasis-type mirage to the energy-thirsty physicist." It is always considerably higher than his accelerator can reach. If the characteristics shown by the data up to 29 GeV persist at higher energies, Asymptopia will not be reached before 25 000 GeV. —GBL

LRL Plans Synchrotron and Storage Ring for Heavy Ions

The AEC has provided $4 million for studies of a multipurpose accelerator to produce beams of ions of any element from hydrogen to uranium with a wide range of energies. It is being planned at the Lawrence Radiation Laboratory in Berkeley. Its designers, Albert Ghiorso, Robert M. Main and Bob H. Smith, call it the "Omnitron" because of its versatility; the accelerator is intended to serve biophysicists and nuclear physicists interested in heavy-ion reactions or medium-energy physics research with light ions. Protons will have a maximum energy of 1.5 GeV, and heavier ions will be able to reach maximum energies from 300 MeV/nucleon to 500 MeV/nucleon; beam intensities will range from 10^{11} to 10^{13} particles/sec depending upon the kind of ion accelerated.

A novel design will be used to obtain these characteristics. The accelerator will consist of two concentric alternating-gradient rings of guide magnets about 36 meters in diameter (see figure); the inner ring will be a synchrotron, and the outer ring will serve as a storage ring. This configuration will permit acceleration in two stages by switching a beam from the inner ring to the outer ring, stripping electrons from its ions, putting it in the inner one and accelerating again. Such a machine can be built within four years for around $25 million. It would provide beams of higher-energy and heavier ions with higher intensity and more precise control over a wider energy range than now available.



OMNITRON will be two concentric alternating-gradient magnet rings. Inner ring is to be a synchrotron, outer one a storage ring. This configuration will permit two-stage acceleration of any kind of heavy ion.