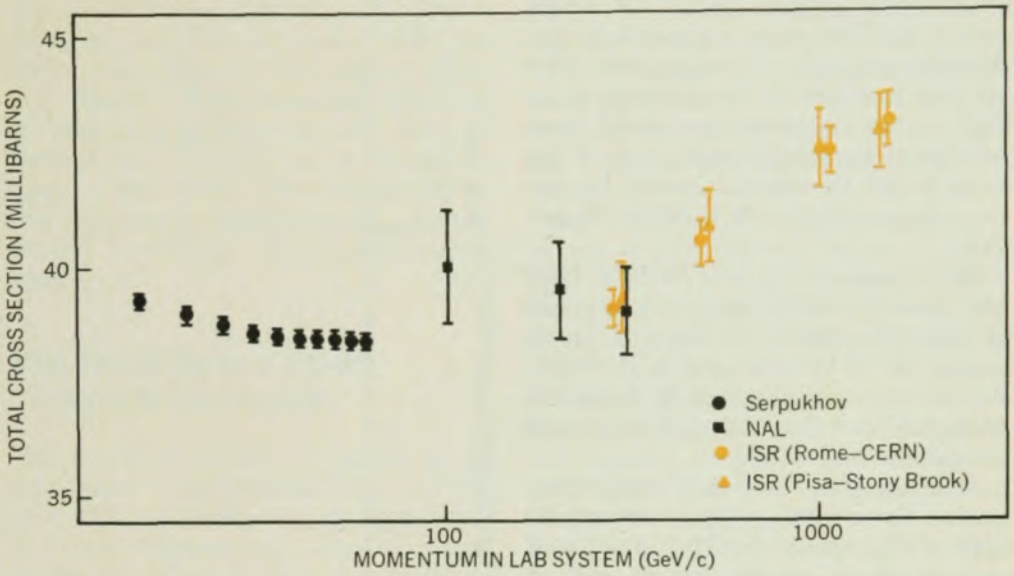
search & discovery

Proton-proton total cross section shows unexpected rise

It has been generally believed for proton-proton collisions that as the energy was raised beyond present experimental limits, the total cross section would continue to be constant at about 39 millibarns. Now CERN has announced that two independent experiments at the CERN Intersecting Storage Rings have found that the cross section increases by about 10% as the center-of-mass energy goes from 23 to 53 GeV, or in equivalent laboratory energies from 300 to 1500 GeV. The increase is consistent with a theoretical prediction made three years ago by Hung Cheng (MIT) and Tai Tsun Wu (Harvard University), who predicted[1] that the total cross section would increase as $a + b (\log s)^2$ where s is the square of the center-of-mass energy.



Proton-proton total cross section as a function of momentum in the laboratory. The new ISR data shows an increase of about 10%, an almost completely unexpected result.

Commenting on the results, C. N. Yang (State University of New York at Stony Brook) said that in some sense the most important practical thing that the proton presents to the world is its size. Now that it turns out to be apparently bigger than was thought, the discovery has a tremendous impact. Until the new results were known, Yang would have said there were theoretical reasons for believing the cross section should be constant. Upon closer examination, he says that they were merely prejudices. The excitement is magnified, Yang feels, by the prediction of Cheng and Wu. In addition there had been some earlier evidence based on an analysis done by G. B. Yodh (University of Maryland), Yash Pal (Tata Institute of Fundamental Research) and J. S. Trefil (University of Virginia) of earlier cosmic-ray data. They reported[2] that the total cross section rises with $(\log s)^2$, and said that at 10^4 GeV incident energy the cross section would be greater than or equal to 48 millibarns. This lower bound, Yodh told us, was based upon a careful and conservative analysis of several independent earth-based and balloon experiments of singly charged spectra. The conclusion that proton-air cross sections must rise could be altered only if different, independent experiments were systematically wrong by large factors, he said. However, because of the inaccuracy of cosmic-ray data it is generally believed, Yang notes, that this analysis was very interesting but not compelling. It would be extremely valuable now, Yang feels, to do

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Superconducting fluctuations at 60K?

A group at the University of Pennsylvania has reported observing superconducting fluctuations in organic solids above 60 K. In a postdeadline invited paper at the March meeting of the American Physical Society in San Diego, Alan J. Heeger, Anthony F. Garito and their collaborators (L. B. Coleman, M. J. Cohen, D. J. Sandman and F. G. Yamagishi) reported finding a conductivity 500 times the room-temperature value in an organic charge-transfer salt based on tetracyanoquinodimethan (TCNQ). The Penn group has been investigating a particular TCNQ salt called (TTF)(TCNQ) and a modified version of it called (ATTF)(TCNQ), and they interpret their data as arising from superconducting fluctuations associated with a tendency toward high-temperature superconductivity in these pseudo-one-dimensional solids.

Although the ground state of the compounds thus far studied is that of a "Peierls insulator" rather than a superconductor, the Penn group proposes a possible mechanism for achieving high-temperature superconductivity based on the electron-phonon interaction and the "Peierls instability," and they outline a prescription for the possible stabilization of the superconducting state in such solid-state systems.

The news of the Penn results had been spreading rapidly a couple of weeks before the APS meeting, with preprints of their paper (submitted to *Solid-State Communications*) being Xeroxed until they were bleached white. A really high-temperature superconductor would of course revolutionize technology. So far the highest-known superconducting transition temperature is 20.8 K, achieved five years ago in niobium-aluminum-germanium by Bernd Matthias and his collaborators. The Penn report has excited great interest, but their theoretical explanation has met with considerable skepticism.

The Penn group has been studying organic charge-transfer salts for several years. Heeger told us they were trying to achieve the metallic state and maintain metallic behavior to low temperatures being "well aware that the electron-phonon interaction must be strong in these narrow-band systems." When they found the extraordinary increase in conductivity in (TTF)(TCNQ) they were sufficiently cautious to sit on their results for over three months until the asymmetric analog of the TTF molecule had been synthesized with the resulting comone-dimensional electronic dielectric response function, that is, to keep it large but not divergent. One way of carrying out this smoothing is to add to the thermal disorder some static, random potentials in the solid by altering the molecular structure and mixing into the lattice weak, random dipoles.

- One wants to hinder the Peierls dimerization, the pairwise interaction in which the uniformly spaced chain of molecules collapses so that one has instead a chain of pairs. To prevent that, one can imagine putting "sticks" between the sites, some bulk that does not allow the molecules to come close together. In this steric-hindrance approach one attaches inert groups onto the molecular sites to keep them from collapsing towards one another.
- The electronic dielectric response function can be smoothed by adding some two-dimensional character to the otherwise one-dimensional chains so that an electron can occasionally go off to the left or right down another chain. Although the system would continue to be strongly one-dimensional, weak two-dimensional coupling should be possible.

In their earlier work the Penn group had decided that to maintain the metallic state in the material they were working on, (NMP)(TCNQ), they would need to replace the NMP cation by a small polarizable molecule. Which one to select became clear through the work of F. Wudl (State University of New York at Buffalo) and his collaborators, who pointed out that the TTF molecule existed and had certain advantages. The TTF cation, which contains sulfur, is not only small and polarizable but also has the possibility of forming metallic chains in the solid.

As a first attempt at stabilizing the superconducting state the Penn group decided to put an asymmetry into the TTF molecule, leading to the new compound (ATTF)(TCNQ). They find that the results on (ATTF)(TCNQ) are reproducible with T_c decreased somewhat, qualitatively as expected.

Although they worked for three months, the Penn group has not yet been able to make single crystals of (ATTF)(TCNQ) big enough for four-probe conductivity measurements. Instead, they developed a new technique for obtaining information on the bulk conductivity properties from compactions of samples. In the measurements on (ATTF)(TCNQ) powder or crystals, Garito told us, a large conductivity maximum is reproducibly observed with indications of $(T - T_c)^{-3/2}$ behavior, but the measurement is limited by the silver paint used in the voltage-shorted compaction device employed. The Penn group feels that the asymmetrized TTF cation has solved the reproducibility problem. They recognize that single-crystal data are clearly needed and are continuing to try to obtain them.

What will the future hold? Heeger feels that if the group's prescriptions are followed, one should be able to stabilize organic high-temperature superconductors. "As high as room temperature?" we asked. "Although room temperature seems unlikely, no one knows really. In the absence of a suitable microscopic description of what's going on, one cannot predict what the limits are. However one thing is clear. We observe superconductive behavior at high temperatures in the form of fluctuations. Now what is needed is hard work, both chemical synthesis and physical measurements, aimed toward stabilizing the organic superconductor." —GBL

Kitt Peak opens up its 158-inch telescope

The ceremony known as "letting in the first light" was recently held for the new 158-inch telescope at Kitt Peak National Observatory. The telescope, which will be the second largest optical telescope in the world when it is dedicated in June, is named the Mayall telescope in honor of Nicholas U. Mayall, director of KPNO for eleven years. The new instrument is expected to be in full operation in October.

The Mayall telescope will have a wider field of view than any other large reflecting telescope—six times wider than that of the 200-inch Hale telescope. One photograph taken through the telescope will give astronomers at least 40 times more sky coverage than the largest presently available and will cover an area about twice the size of the moon. Electronic image detectors will be used extensively on the telescope, which will be used for observation of faint quasars and pulsars as well as radio and x-ray sources that radiate in the visible range.

The telescope itself weighs 375 tons and is perched on a hollow cylindrical pier 37 feet wide and 92 feet high. This is a higher pier than is normally used; it was needed to get the instrument above the atmospheric turbulence caused by rising hot-air currents at the site. A circular building 105 feet in diameter and 185 feet high houses the instrument. It has a 105-foot diameter dome that weighs 500 tons and can rotate 360 deg on 32 trucks that travel on a circular rail.

The 15-ton primary mirror is made of fused quartz, which has a low coefficient of thermal expansion, and is set in a horseshoe-shaped yoke that has an outer bearing surface 41 feet in diameter.

The telescope has a "flip secondary" —a ring that supports a camera on one side and a secondary mirror on the other. This ring is located at the prime focus and permits the telescope to be switched rapidly from operation at the prime focus to Cassegrain or coudé focus operation. This feature is rarely found in large telescopes.

The total cost of building the telescope was $10 million, supplied by the National Science Foundation. It is operated by the Association of Universities for Research in Astronomy, which is responsible for operating KPNO under contract with NSF. Observing time will be open to scientists throughout the country, regardless of affiliation.

Another telescope, which is nearly a twin to the Mayall instrument, is being built at the Cerro Tololo Inter-American Observatory in Chile. This instrument is expected to be operating in 1975 and will be one of the major instruments for studying the southern sky. Another telescope, with a 236-inch mirror, is being constructed by the Soviet Union near Zelinchuk on the northern slopes of the Caucasus Mountains. When completed it will be the largest telescope in the world, relegating the Mayall size of 158 inches to third largest.

Total cross sections

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a more controlled cosmic-ray experiment studying proton-nucleus cross sections at 10^5 GeV.

In an attempt to calibrate the excitement in the high-energy physics community, Yang compared the ISR results with parity violation in 1957 and *CP* violation in 1964. Although he feels that probably the new result is as yet less exciting, it could lead to insight that may prove eventually no less important.

As Victor Weisskopf (MIT) points out, the expectation that all results become constant at a high enough energy has again been thwarted, and such a region in fact may never be reached.

Experiments. In one of the two experiments done at the ISR, reported[3] by a collaboration between Sezione di Pisa of INFN, the Istituto di Fisica of the University of Pisa, the Scuola Normale Superiore and the State University of New York at Stony Brook, the experimenters determined the total cross section from the measured interaction rate and the machine luminosity, which represents the overlap of the two beam fluxes in the intersection region. To measure the luminosity the Pisa–Stony Brook collaboration uses the so-called "van der Meer method," which consists in displacing the beams vertically with respect to each other and measuring the monitor rate of beam-beam events as a function of relative beam displacement. Although this method is the primary one employed, the team checked the luminosity with other methods and expects to refine the checks further in the next few months. By now they believe they know the luminosity to an error of 2%. They find that the total cross section increases by almost 4 millibarns between 23 and 53 GeV (see figure).

The other ISR experiment, reported[4] by a collaboration between the Physics Laboratory of the Istituto Superiore di Sanità, the Sezione Sanità of the INFN, Rome, and a group at CERN, did an elastic-scattering measurement at angles around 6 millirad. They used the van der Meer method to determine the luminosity and establish the absolute scale of the differential cross section, extrapolated to $\Theta = 0$ deg using the measured Θ dependence of the differential cross section and then calculated the total cross section from the optical theorem. The calculation assumes that spin effects are negligible. The Rome-CERN group finds that the total cross section increases by (4.1 ± 0.7) millibarns from 23 to 53 GeV.

In their paper the experimenters remark that the experiment by S. P. Denisov and his collaborators shows that the K^+-p cross section increases from a constant plateau of 17 millibarns below 20 GeV/c to about 18 millibarns at 55 GeV/c. Examining the trend of the antiproton-proton cross section they say it is conceivable that it passes through a minimum at s greater than about 300 GeV^2 before rising towards the p-p cross section, if there is a common high-energy limit as required by the Pomeranchuk theorem. They then speculate that the K^+-p, p-p and $\bar{p}$-p total cross sections begin to increase at energies connected with the size of their plateau cross sections; they note that the rise would appear at lower energy the smaller the cross section of the plateau. Furthermore the total cross sections for K^--p, π^+-p and π^--p will rise appreciably at laboratory momenta above 60 GeV/c, they say, but in all three cases at momenta lower than that at which the p-p cross section begins to rise.

Theory. In 1957 Werner Heisenberg, discussing bremsstrahlung in electromagnetic production, published an intuitive reasoning that proton-proton processes that produced many particles would have a slowly rising cross section varying as $a + b\,(\log s)^2$.

M. Froissart, in 1961, established a bound on the total cross section, an upper limit for the total proton-proton (or any other reaction, π-p, K-p) cross section; the limit was $a + b\,(\log s)^2$. This limit means that the cross section could be constant, could even go down with energy, but could not rise faster than $(\log s)^2$. Froissart's result was put on a more rigorous basis by André Martin. The limit is based on unitarity and analyticity.

About five years ago Cheng and Wu began publishing a series of papers based on their study of field theory. Using ideas that are rigorously true in electrodynamics and applying them to strong interactions, they assumed a vector gluon field that transmits the force between spinor partons. The vector particles are like photons except that the gluons may have mass. Cheng and Wu had studied the behavior of the contributions to cross sections from individual Feynman diagrams at extremely high energies and tried to deal with the infinite-energy behavior of the contribution of individual Feynman diagrams by trying to identify those Feynman diagrams that play a leading role when the energy increases by making some plausible assumptions about the behavior of certain Feynman diagrams.

Their 1970 paper made a number of predictions about cross sections at infinite energy, which at the time did not excite much interest in the physics community because of the paper's speculative nature. Now that the CERN results have been reported, the theory is being enthusiastically reexamined. Although the ISR data does not explicitly show a $(\log s)^2$ behavior, it is consistent with the increase predicted by Cheng and Wu.

Cheng and Wu interpreted their results in the following way: In a bremsstrahlung-like process the proton-proton collision would become more and more absorptive at all impact parameters. Their physical picture is that the proton at high energy (center-of-mass energy much higher than the rest mass) looks like a big black disc with a small gray fringe around it whose width is approximately a constant. By black they mean that any beam that hits a target will be completely absorbed; by gray they mean there will be partial absorption. There is no sharp boundary between the two regions. Once they got this picture they and James K. Walker (National Accelerator Laboratory) developed a phenomenological model to predict what would happen at ISR energies; their predicted increase, which they reported last September at the high-energy physics conference in Chicago, is somewhat less than what has now been observed.

Several predictions follow from the physical picture. Classically the total scattering from such a black disc will increase as the radius squared. They say that the radius is proportional to $(\log s)$ if the energy is very high.

A second prediction is that at extremely high energies (far beyond that at the ISR), when the gray fringe becomes small compared with the black disc, the elastic scattering will become half of the total cross section. At the moment the elastic cross section is roughly 20% of the total cross section and has been going down very rapidly at Brookhaven and Serpukhov energies (30 and 70 GeV, respectively). But the Rome-CERN collaboration, in the experimental results just announced, has found the elastic cross section is rising, although with comparatively large error bars.

A third prediction is that the ratio of the real to the imaginary part of the forward scattering amplitude will become positive at sufficiently high energy. Until a few months ago all measurements gave a negative value for this ratio. Then a CERN-Rome group found a slightly positive value for the ratio, although the error bars are still very large, Cheng and Wu say. They predict that the ratio although positive will eventually vanish.

A fourth prediction already made in 1968 in the droplet model is that there will be a dip in the diffraction pattern for elastic scattering. A similar dip has been observed at the ISR by a different group. Cheng and Wu have also made other predictions.

"Does your theory have anything to do with partons?" we asked. Not if one requires that partons be pointlike and have fractional charge, Cheng and Wu said. "But many aspects of the parton model are consistent with our theory. Indeed many features of the other models of high-energy scattering, for example the Regge-pole model and the droplet model, are also consistent with our theory, while the origin of the important differences between our theory and others is well understood," Cheng said. "In this respect it is well to point out that all of these models can accommodate for the rising of the total cross section and in the context of the Regge-pole model and the droplet model some work in this direction has already been done by V. N. Gribov and K. A. Ter Martirosyan, S. C. Frautschi and B. Margolis, J. Finkelstein and F. Zachariasen. "With the increasing cross section we see in the future a merging of all schools of high-energy scattering theories." —GBL

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