Diffraction

Diffraction: From Compact Discs...

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Look at the glints of color from the surface of a compact disc when you hold it up to a light at certain angles. The colors result from a phenomenon called diffraction, in which small ripples on the surface of the compact disc break up white light, carried by particles called photons, into the colors of the rainbow. Red and blue appear in different places because they correspond to waves of different wavelength.

A classical demonstration of diffraction that more closely resembles some high-energy physics experiments is to pass light through a narrow slit or past a small obstacle. You can see this for yourself. On a dark night look at a small, bright, distant light; the smaller, brighter and farther the better. Place two small pieces of cardboard side by side but overlapping and slightly angled to form a slit, and put this sharp vee just in front of your eye. If your focus is relaxed you will see faint fringes that spread out more as you look towards the narrowest part of the slit. Experiment with this; it can even work using your thumbnails.

This behavior of photons glancing off the surface of a compact disc or passing obstacles is relatively easy to demonstrate and explain. But whereas physicists understand the diffraction of visible-light photons, the diffraction of particles such as protons is still rather mysterious. In an effort to understand particle diffraction, Fermilab and Argonne National Lab researchers organized a conference last September.

Physicists have learned that all particles—electrons or protons, neutrinos or quarks—can undergo diffraction. When two protons, or a proton and an antiproton, collide, the simplest thing that can happen is that they emerge with no loss of energy but with slightly changed direction. This is an example of "elastic scattering."

At the Tevatron, the collision of a proton and antiproton can give rise to many different final states, some with only two particles but usually with many more. **Figure 1** shows two particles producing many particles, symbolized by several lines emanating from the collision region (the oval). The symmetry of the interaction process means that we can reverse the direction of time in the diagram; in other words, many particles can also interact to form two. **Figure 2** shows a "special case" of all the possible outcomes of a proton and an antiproton interacting: they make many particles, which recombine so that the final state is again a proton and antiproton. Intermediate states, shown schematically by the lines between the ovals, are called "virtual."

An alternative view of the proton-antiproton collision is to consider that something carries momentum from the scattering proton to the antiproton. This exchanged "thing" is called the pomeron, after the Russian physicist Isaak Pomeranchuk (1913-1966). Thirty years ago Pomeranchuk proved important and fundamental theorems about particle and antiparticle scattering at very high energies. It is this theoretical entity, the pomeron—not really a particle but sometimes behaving like one—that we hope to understand.

We can distort Figure 2 to represent the virtual or intermediate state as a "ladder" linking the particles (**Figure 3**). We know that protons are composites of quarks and carriers of the strong force, known as gluons, so the "ladder" must consist of these. We can think of this diagram as representing the exchange of a clump of gluons, with perhaps some quark-antiquark pairs, between the scattering protons.

...to *W* bosons

Figure 1

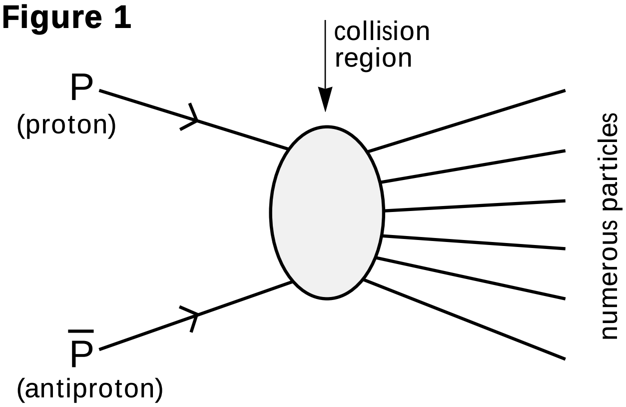


Figure 2

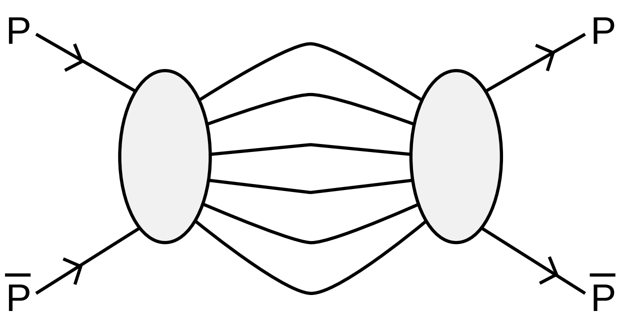


Figure 3

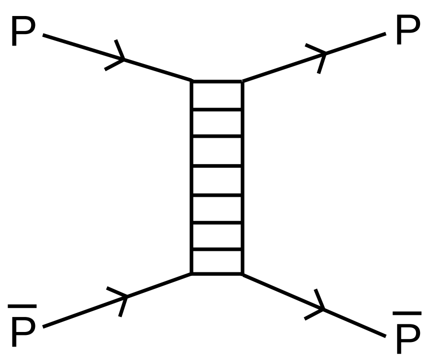
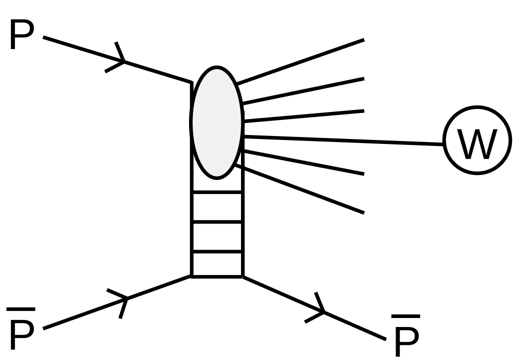


Figure 4



Another interpretation of the scattering process is that in most proton-antiproton collisions one gluon is exchanged, but then the protons or antiprotons cannot escape unchanged; there would be a strong "gluonic" force between them which would cause many new particles to be produced. But if *two* gluons are exchanged their gluonic forces can cancel out, and the protons and antiprotons can escape with just a small deflection. While two gluons are being exchanged they "talk to each other" (to use a typical physicist's phrase), exchanging more gluons, and the diagram of the interaction then looks like a ladder. Figure 3 is a good model of the pomeron, although it is difficult to calculate its behavior from basic theory.

Often when a pomeron is exchanged, as in **Figure 4**, one of the protons transforms into many particles. This is the same "two particles to many" process shown in Figure 1, but for a pomeron-proton collision. Both colliding-beam experiments at Fermilab, CDF and DZero, are studying such events and unraveling the structure of the pomeron. This study was pioneered by an experiment (UA8) at CERN, which found jets—sprays of particles—being diffractively produced. The Tevatron has three times the energy of the CERN machine and can do this physics with higher event rates and higher energy jets. CDF researchers are intrigued by new results from the analysis of 1991-1995 data on diffractive scattering pomeron-proton collisions. These events produce the very massive *W* boson, which is 85 times heavier than the proton. The *W* boson is a particle that carries the weak force. These results confirm that the pomeron contains quarks; gluons cannot make *W* bosons directly. Physicists at the electron-proton collider HERA in Germany study pomeron-photon collision events. Like the *W*, the photon does not interact directly with gluons, and from the rate of their events they conclude the pomeron has quarks. Both CDF and ZEUS (an experiment at HERA) conclude that a pomeron consists of about 60 percent gluons and 40 percent quarks.

The task now is to study pomerons much more accurately and to compare the results with those from HERA. Does it still make sense to think of this enigmatic object, the pomeron, as if it were a particle? Will HERA's measurements, using a photon as a probe, give the same answers as Fermilab's, using a proton as a probe?

One of the reasons physicists are interested in pomerons is that they appear to have a close relationship with vacuum. Vacuum is what is left after all the real particles are removed from a box; the space, physicists believe, is not empty, but teeming with so-called "virtual" particles that flit into and out of existence. In some high energy proton-antiproton collisions the original two particles lose just a small percent of their energy, which appears as a cluster of particles created apparently out of the vacuum in a phenomenon called vacuum excitation. Another viewpoint is that events of this kind are the result of two particle-like pomerons colliding. Events like these have hardly been studied at the Tevatron, though CDF and DZero both observe them. Some particle physicists think the study of pomerons would be a very interesting project for Fermilab's next collider run. ■