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Cross Section

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The concept of cross section is the crucial key that opens the communication between the real world of experiment and the abstract, idealized world of theoretical models. In a high-energy physics experiment, we specify interactions of elementary particles quantitatively in terms of cross sections. The cross section is the probability that an interaction will occur between a projectile particle—say, a proton that has been accelerated in the Tevatron—and a target particle, which could be an antiproton, or perhaps a proton or neutron in a piece of metal foil.

We can measure the probability that two particles will interact in experiments. We can also calculate this quantity in a model that incorporates our understanding of the forces acting on a sub-atomic level. In the famous experiment in which Rutherford studied the scattering of alpha particles off a foil target, the cross section gives the probability that the alpha particle is deflected from its path straight through the target. The cross section for large-angle scattering is the fraction of alpha particles that bounce back from the target, divided by the density of nuclei in the target and the target thickness. The comparison of the measured cross section with the calculated one verified the model of the atom with a minute, massive center, carrying an electrical charge.

We can picture the cross section as the effective area that a target presents to the projected particle. If an interaction is highly probable, it's as if the target particle is large compared to the whole target area, while if the interaction is very rare, it's as if the target is small. The cross section for an interaction to occur does not necessarily depend on the geometric area of a particle. It's possible for two particles to have the same geometric area (sometimes known as geometric cross section) and yet have very different interaction cross section or probability for interacting with a projectile particle.

During wartime research on the atomic bomb, American physicists who were bouncing neutrons off uranium nuclei described the uranium nucleus as "big as a barn." Physicists working on the project adopted the name barn for a unit equal to 10^{-24} square centimeters, about the size of a uranium nucleus. Initially they hoped the American slang name would obscure any reference to the study of nuclear structure; eventually, the word became a standard unit in particle physics.

Today, although experimental techniques and theoretical calculations have considerably increased in complexity compared to the early days of scattering experiments, the concept which links theory and experiment has not changed. In the Tevatron, for instance, we measure the probability of producing a pair of top quarks in a proton-antiproton collision. We measure this production cross section by counting the number of top quark events observed in the detector and by knowing the time-integrated luminosity, the product of the number of particles per unit time in the proton and antiproton beam, per area of the beam. By comparing the top quark production cross section with predictions, which are based on a model of elementary particles and their interactions, we probe our understanding of the strongest known force between elementary particles. ■

Photo by Reidar Hahn

Can't hit the broad side of a barn? Try hitting an atomic nucleus. The unit of cross section is the "barn," equal to 10^{-24} square centimeters. This barn, one of many on the Fermilab site, is located at Kautz road.