NAL PROPOSAL No. 56

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MEASUREMENT OF TOTAL CROSS SECTIONS ON HYDROGEN AND DEUTERIUM

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ABSTRACT

Total cross sections of $\pi^{\pm}$, $K^{\pm}$, p and $\overline{p}$ on hydrogen and deuterium are to be measured at about eight energies between 20 GeV and the maximum available energy. An accuracy of about one part in one thousand will yield the energy dependence of cross sections, comparisons of cross sections within SU(3) supermultiplets, and stringent tests of high energy limiting theorems.

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We propose, as a continuation of our studies at Cosmotron and AGS energies, to measure the total cross sections of π^+ and π^-, K^+ and K^-, and p and $\bar{p}$ on hydrogen and deuterium from about 20 GeV to the maximum energy available at NAL. Accurate measurements of this basic parameter of strong interactions are an essential ingredient to the understanding of phenomena at very high energies; their behavior as a function of energy is a direct test of general limiting theorems.

It does not seem necessary, in view of the wide literature on the subject, to present a detailed argument on the possible interpretations to be given to the energy dependence of the total cross sections which might be observed. We mention only a few of the general physical principles which can be tested, namely:

(1) The Pomeranchuk theorem which predicts that $\sigma(\pi^+p) = \sigma(\pi^-p)$; $\sigma(K^+p) = \sigma(K^-p)$; and $\sigma(pp) = \sigma(\bar{p}p)$ at sufficiently high energy.

(2) The Pomeranchuk theorem which predicts that $\sigma(pp) = \sigma(pn)$; $\sigma(\pi^{\pm}p) = \sigma(\pi^{\pm}n)$, etc., at sufficiently high energy.

(3) Charge independence of strong forces which predicts $\sigma(\pi^+d) = \sigma(\pi^-d)$ at all energies.

As in our previous experiments, the deuteron Glauber-Wilkin shielding correction is determined from the pion-proton and pion-deuteron cross sections. The cross sections as a function of energy for each pure isospin state can then be deduced for K mesons, protons and antiprotons.

The imaginary part of the forward scattering amplitude as a function of energy is computed directly. The real part of the forward scattering amplitude can be computed via the dispersion relations and tested with considerable accuracy against direct measurements of this quantity. The real and imaginary amplitudes give directly the $\pi^- p \rightarrow \pi^o n$ and $\pi^+ n \rightarrow \pi^o p$ charge exchange cross sections and the regeneration of K_S^o from K_L^o on hydrogen and deuterium which can be tested by other experiments.

It has been noted that the new measurements available from Serpukhov which extend earlier work at the AGS and at CERN to the 50-70 GeV region already raise some doubt as to whether the limiting theorems of constancy of total cross section and equality of cross sections for members of the same SU(3) supermultiplets can be applied. Both the increased energy range at NAL and the possibility of increasing considerably the accuracy of the data can provide a much more severe test of current ideas.

Experimental Method

We wish to stress the need for, and the possibility to achieve, great accuracy in the measurements. In order to be able to make the comparisons of cross sections indicated in the introduction, it is necessary that:

(1) The energy dependence of a given cross section over the full range should have a relative accuracy of 10-30 μb. The lower value applies for the more abundant particles ($\pi^{\pm}$,p) and the upper for the less abundant ($K^{\pm}$,$\bar{p}$). Such accuracy requires excellent angular resolution for the extrapolation of measurements of partial cross sections at finite solid angles to zero solid angle, and we believe this can be aided by the use of proportional wire chambers (PWC) in addition to the standard scintillation counters.

(2) The comparison of the same isospin multiplet on a given target, say $\sigma(\pi^{\pm}p)$, to an accuracy of 20-40 μb requires extreme stability not only

of electronic and magnetic components, but also of target density. Corrections for multiple and single Coulomb scattering as well as beam contamination at this level must be known with sufficient accuracy from the data, or subsidiary measurements.

(3) For the absolute cross sections on hydrogen and deuterium, we believe it reasonable to aim at an accuracy of about one part per thousand. In addition to the requirements of (1) and (2) above, this accuracy requires that the absolute density of the hydrogen and deuterium targets (as well as their physical length) be known to better than one per mil. We also expect to recheck and, if necessary, remeasure the vapor pressure vs. density curves for deuterium which may have been the cause of previous discrepancies between various laboratories in absolute cross section measurements.

We detail now the physical layout and the methods by which we consider that we can achieve the accuracies listed above.

A schematic layout of the apparatus is shown in Fig. 1. The incoming particle is defined in direction by PWC 1, PWC 2, and PWC 3, each of which consists of a module comprising four planes of proportional wire chambers. The Cerenkov counter (or counters) C1, placed before the quadrupoles Q1 and Q2, measures the velocity of the incoming particle and, together with the beam momentum, defines its identity. The targets (T) consist of three identical modules (one for hydrogen, one for deuterium, and one a dummy) capable of being placed easily in the beam in rotation. The unscattered particles and those which scatter less than an angle θ_{max} are detected in modules PWC 4 and PWC 5. The large absorber block (A) following PWC 5 is used to define the muon contamination as described below. Scintillation counters SC1, SC2, SC3 define the beam and, in coincidence with C1, provide the trigger for the PWC modules. The counter set SC4 consists of several counters of different diameter to measure the transmitted beam in the standard way. Counter SC5, together with the beam defining counters, measures the muon contamination of the beam. The counter set SC4, PWC 5, A, and SC5 are mounted on a cart which is moved along the beam line on rails. For each momentum the cart is moved so that the transmission counters SC4 subtend the same range of -t.

For scattering angles which correspond to momentum transfers larger than approximately 0.1 $(GeV/c)^2$, the partial cross sections are measured in the standard way by the transmission counters SC4. Thus full advantage can be taken of the high rate of data acquisition for which counters are best suited. For momentum transfers smaller than approximately 0.1 $(GeV/c)^2$, the PWCs are interrogated by a coincidence of the beam telescope and counters of SC4 corresponding to this range of momentum transfer. The great spatial resolution of the chambers will make possible accurate extrapolation for small momentum transfers. The PWCs are limited to a few hundred events per pulse by data acquisition and are thus used only to provide the slope at small angles.

We shall provide a PDP-15 computer to monitor all relevant parameters of the experiment including beam magnets, target vapor pressure, high voltages, beam spill, etc. The buffer memory will be read onto tape between pulses when all parameters for that pulse fall within tolerance. Thus the need, for example, for long runs under rigid beam spill requirements can be eliminated, bad pulses simply being erased from the buffer without being accumulated on tape. It is our experience that this method will maintain rigid control of the parameters pulse by pulse, making maximum use of beam time, and keep the data in statistical control. In normal practice, long runs often must be eliminated post facto which results in inefficient beam utilization.

For the coordinate data, scattering angles will be computed on and off line as required to accumulate the data for the particles scattered at small angles. From these data, accurate extrapolation to zero solid angle should be possible.

Measurements

We propose initially to measure σ_T for the six particle types with the two targets of H and D at each of eight energies, a total of $6 \times 2 \times 8 = 96$ measurements. Depending on the energy at which the accelerator operates, the measurements would be spaced at intervals between 25 and 50 GeV. Absorption cross sections for complex nuclei can be measured during the course of the experiment with negligible increase in running time.

For purposes of estimating rates, we take a conservative value of 1.5×10^5 particles traversing the apparatus per pulse. Such a value is tolerable for a spill length of 300-500 msec and would have to be adjusted to prevailing conditions. Special electronic gating techniques which we have used before will prevent pile-up in scalars and insure PWC recovery.

For a target length of 5 meters, the fractional statistical error is given approximately by

$$\frac{\Delta\sigma}{\sigma} \approx \frac{3}{\sqrt{N}}$$

where N is the total number of incident particles. Thus, to achieve a statistical precision of one part in 2000 requires approximately 4×10^7 incident beam counts. The total beam per hour would be

$$1.5 \times 10^5 \times 15 \times 60 \approx 10^8,$$

so that a typical data run would be about fifteen minutes for $\pi^{\pm}$ and p, and about ten to twenty hours for $K^{\pm}$ and $\bar{p}$.

For $\pi^{\pm}$ and p with short data runs, we know from experience that the time required will be completely dominated by setting bending and focusing magnet currents and Cerenkov counter pressure, by efficiency checks, by multiple runs to crosscheck stability, and by dummy target runs. We also estimate that for the extrapolation about 10^6 PWC events are needed. Based on 500 events per pulse, ~2 hr is required for this purpose. Taking all into account, each data point will need ≈ 6 hr.

For the $K^{\pm}$ and $\bar{p}$, where the effective beam is reduced between a factor of 30 and 100, the data accumulation will require a more significant fraction of the time. An average time of 15 hr per point is estimated.

The total time required is then ≈ 1,000 hours.

Special Equipment

I. Particle Identification. The incident beam particle will be defined by means of Cerenkov counters, which we are prepared to design and construct. A differential Cerenkov counter can be built of sufficient resolving power for our needs, but its detailed design is greatly affected by the divergence of the beam in which it is placed; for instance, with a beam divergence of ±0.2 mr a differential counter of length ~20 meters would be sufficient. Since the counter and beam design are so interdependent, we would be willing to assist in the latter if requested. In a worst case where a beam of sufficient parallelism is not available, the experiment could still be carried out adequately using threshold Cerenkov counters.

II. Beam. The beam which has been considered for this proposal was the 200-GeV/c beam described by D. Reeder and J. MacLachlan in SS-41. The solid angle of acceptance, $\Delta\Omega$, was taken to be 10^{-6} μ sr. For 10^{12} protons interacting on the production target the available range in momentum spread $\pm$ 0.017% $\leq \frac{\Delta p}{p} \leq$ 1% would be adequate to provide 1.5 x 10^{5} particles per pulse over the full momentum range for a positive beam and up to 160 GeV/c for the negative beam.

III. Targets. The targets would be similar to those developed in our last few total cross-section experiments. The vessels containing the liquid hydrogen and liquid deuterium are contained inside an outer cylinder filled with liquid hydrogen. The vapor pressure of the outer liquid would be regulated to within $\pm$0.07 psi. This pressure fluctuation would correspond to a density fluctuation of $\pm$0.05% for the inner hydrogen and deuterium. The absolute densities and lengths of the targets will be established to better than $\pm$0.1%. A third, dummy target would be used for background subtraction. The optimum target length is calculated to be about five meters; a target diameter of three inches may be sufficient.

Since we anticipate the long-term need by NAL for Cerenkov counters and targets of the general type required for this proposal and since we have accumulated substantial experience over several years in the design of this type of equipment, we propose to design and build them and to turn them over to NAL for general use following the experiment, should this be desirable. Alternatively, we are prepared to utilize NAL-designed equipment, if available. Methods of meeting special NAL requirements for safety, etc., and financing arrangements need to be worked out with NAL, BNL and the AEC if we are to undertake design and construction responsibility.

Personnel

In addition to the scientists listed by name on the proposal, we expect to be joined by approximately 2 Ph.D.-level staff members and 1 graduate student from Rockefeller University. We would be prepared to add a few additional collaborators from NAL or other universities.

Related Experiments

Except for overlap with existing data at lower energies from BNL, CERN and Serpukhov for checking purposes, most of the data will be unique to NAL. The CERN ISR can, in principle, measure p-p total cross sections over the same range. Two experiments have been approved there for this purpose.

Time Scale

Approximately one year will be required to build and test the necessary equipment. Design could begin when approval is indicated.

Summary

We believe that measurements of the total cross sections will play a basic role in the understanding of strong interactions in the new energy range and that the need for accuracy must be stressed if clear conclusions are to be drawn. Moreover, we regard it as essential that the full set of the measurements be made in a consistent manner to permit cross comparison.

The beam requirements on intensity and dispersion in momentum are not severe. Our electronics is designed with special precautions to allow us to take satisfactory data under varying duty cycle conditions. For these reasons we believe the proposed work could be undertaken at a relatively early stage following accelerator turn-on.

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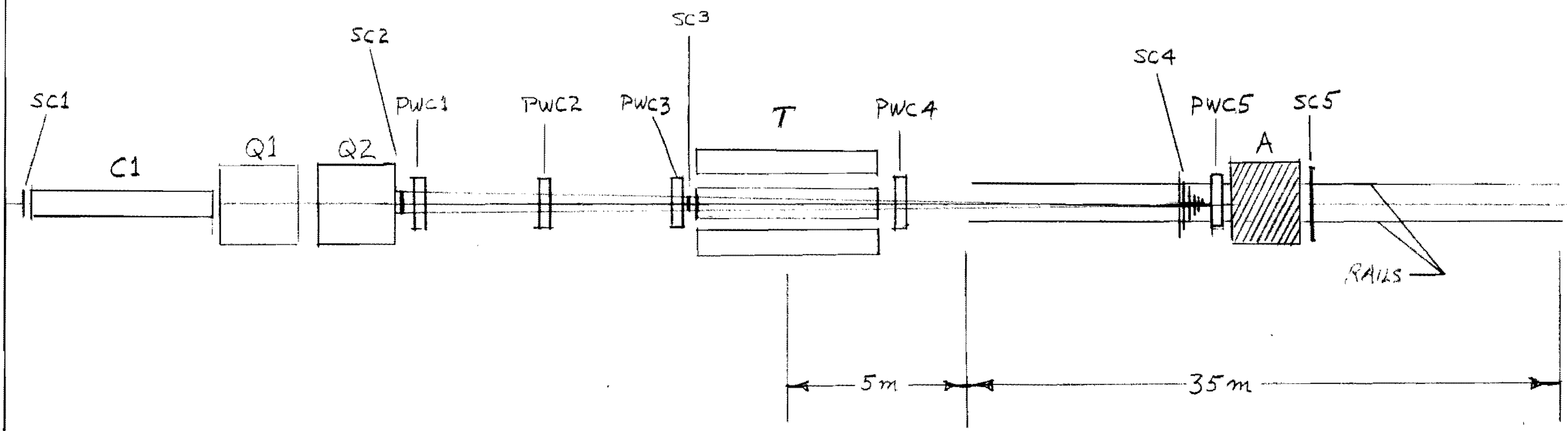

FIGURE 1