MASTER

TECHNICAL PROGRESS REPORT

Experimental Studies of
Elementary Particle Interactions at High Energies

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I. INTRODUCTION

Three major experimental programs, one at the CERN ISR and two at FNAL, have published important new results during the past year. These results together with a general progress report on the Rockefeller University experimental elementary particle research program will be described. The work at FNAL will be discussed in Section II, at the CERN ISR in Section III and at BNL in Section IV.

II. RESEARCH PROGRAM AT FNAL:

A. Total Cross Section Experiment:

In early 1974 the data taking phase began of an experiment to measure the total cross sections of all available hadrons on hydrogen and deuterium. These consisted of measuring the twelve cross section $\sigma_T(pp)$, $\sigma_T(\bar{p}p)$, $\sigma_T(\pi^+p)$, $\sigma_T(\pi^-p)$, $\sigma_T(K^+p)$, $\sigma_T(K^-p)$, $\sigma_T(pd)$, $\sigma_T(\bar{p}d)$, $\sigma_T(\pi^+d)$, $\sigma_T(\pi^-d)$, $\sigma_T(K^+d)$, and $\sigma_T(K^-d)$ as a function of momentum between ~ 20 GeV/c and the highest available momentum (≤ 400 GeV/c). Except where limited by statistics, a precision measurement was planned to give relative accuracy of $\sim 0.3\%$ and absolute accuracy of $\sim 0.4\%$.

These measurements have now been completed for all the secondary particles with energies available from a target bombarded by 300 GeV primary

protons. The first results were published in two recent papers^{1,2}. A further paper with the complete data is in preparation³. All of the measurements are shown in Fig. 1. It is evident from the figure that all cross sections have stopped decreasing and, except for $\sigma_T(\bar{p}p)$ and $\sigma_T(\bar{p}d)$, all increase with increasing momentum. Thus the phenomenon of increasing cross sections, first observed for $\sigma_T(pp)$ at the ISR⁴, now appears to be a general feature of strong interactions.

Since the momentum range covered is large for several varieties of incident and target particles, several other important conclusions can be derived from the data: (1) The cross section difference between particle and antiparticle on the same target [e.g., $\sigma_T(pp) - \sigma_T(\bar{p}p)$] decreases with momentum as p^{-n} , with $n \approx 1/2$. This feature is shown in Fig. 2. Such a behavior was predicted by Pomeranchuk⁵. The precise behavior is in excellent quantitative accord with the Regge model⁶. (2) The equality of the cross sections $\sigma_T(\pi^+d)$ and $\sigma_T(\pi^-d)$ is a precise check of charge symmetry at the level of $\pm 0.2\%$. (3) The total cross sections on neutrons can be derived from comparison of the data on deuterium and hydrogen with the help of Glauber theory. In fact, at present, the result is limited more by the approximations in the theory than by the measurement errors. The deduced values of $\sigma(pn)$ appear to behave like $\sigma(pp)$ and are in approximate agreement with direct measurements of $\sigma_T(np)$ ⁷.

It is expected that in 1975 a proton beam of 400 GeV will be available in the meson area and that the energy range of the measurements can be extended.

FIGURE 1

Figure 2 - The differences between particle and antiparticle cross sections are decreasing with increasing energy. This is in agreement with the Pomeranchuk theorem which states that the differences become zero at infinite energy.

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B. Proton-Proton and Proton-Deuteron Elastic and Inelastic Scattering:

In 1973, we completed measurements of p-p elastic scattering from 8 to 400 GeV for $0.001 < |t| < 0.12(\text{GeV}/c)^2$. From these data we obtained the slope of the diffraction peak and the ratio ρ of the real to the imaginary scattering amplitude^{8,9}. The data showed that ρ increased from negative values, crossed zero near 260 GeV, and became positive thereafter. We then noted that this behavior was consistent with the behavior predicted by the dispersion relations for rising $\sigma_T(pp)$ and $\sigma_T(\bar{p}p)$, approaching each other as p^{-n} .

It is interesting to note that our 1974 measurements of $\sigma_T(pp)$ and $\sigma_T(\bar{p}p)$, described in Section IIA above, show the predicted behavior. We can in fact now reverse the process and calculate ρ from the σ_T data. The results¹⁰ are in excellent quantitative agreement.

In 1974 we completed planned measurements on p-p inelastic scattering and obtained a large amount of data on elastic and inelastic p-d interactions. The p-d data covers the energy range from 50 to 400 GeV, the $|t|$ range from 0.03 to $0.12(\text{GeV}/c)^2$, and the m_X^2 range up to $35(\text{GeV})^2$. For elastic scattering the slope parameter b for p-d is shown¹¹ in Fig. 3. It is consistent with a logarithmic dependence on s , and from it we may deduce the deuteron elastic form factor.

The most interesting new results came from an analysis of the behavior for inelastic scattering of the invariant double differential cross section¹¹

$$s \frac{d^2\sigma}{dt dm_X^2} = f(s, m_X^2, t) \quad (1)$$

The large range in s , the square of the c.o.m. energy; in t , the square of the four-momentum transfer; and in m_X^2 , the square of the missing mass allows us to make quantitative comparisons with the diffraction dissociation model and triple Regge theory. The results may be summarized as follows: (1) Within $\sim 10\%$, the invariant cross section is independent of energy for our range of $|t|$ and m_X^2 . This behavior is in accord with predictions of the diffraction dissociation model. (2) At fixed m_X^2 , the $|t|$ dependence is exponential ($e^{-b(m_X^2)|t|}$). b is a function of m_X^2 which decreases from ~ 18 at $m_X^2 = 1.8$ to ~ 5.5 for $m_X^2 > 6$. (3) If the deuteron form factor is divided out, the cross section integrated over $|t|$ behaves approximately like $d\sigma/dm_X^2 = A/m_X^2$ with $A \sim 0.7$ mb. This behavior is illustrated in Fig. 4. It is consistent with the triple Regge theory with Pomeron exchange dominating the process for our range of variables¹². (4) Where the range of variables overlap, inelastic pp and pd cross section behavior agree when the deuteron form factor is taken into account.

Measurements will be extended to larger values of m_X^2 early in 1975.

III. RESEARCH PROGRAM AT THE CERN ISR:

Analysis of the Phase I CCR experiment was completed in 1974. The result in 1972-73 was the discovering that π^0 -mesons with large transverse momentum are produced near 90° much more copiously at high energies than had been expected¹³. It has been suggested that such a phenomena

$$m_x^2 \int_t \frac{1}{F d(t)} \frac{d^2 \sigma}{d m_x^2 dt} dt$$

p_L GeV/c
 ○ 150
 △ 260
 □ 385

(mb)

Figure 4 - The integral of the inelastic cross section over t .

might be expected theoretically if there were a small-distance, possibly quark-like, structure of the nucleon¹⁴. In this circumstance, strong dynamical correlations (jet-like structure) might be observed between the produced particles. Despite the limitations of Phase I in solid angle and the lack of charged particle momentum measurement, the Phase I CCR data were carefully analyzed for such effects. Strong correlations were indeed observed in π^0 - π^0 and in π^0 -charged particle emission when a π^0 has large p_T ^{15,16}. Although some of the correlations observed are consistent with kinematic effects only, some are clearly dynamical in origin. This data, although suggestive, does not appear to be decisive as to the origin of the large p_T phenomenon. These studies will be continued with a much improved apparatus in a Phase III CCOR experiment at the end of 1975.

A Phase II CCRS experiment, in collaboration with Saclay, has been completed in 1974 although some aspects of the data are still under analysis. The most important result so far is the first demonstration of "direct" electron production at the ISR¹⁷. The data is shown in Fig. 5. For $1.7 < p_T < 4.0$ GeV/c, the ratio of electrons to pions is $\approx 10^{-4}$. This value is the same as that observed in experiments at FNAL¹⁸. We have also placed an upper limit on the cross section for the production of ϕ^0 -mesons which is such that it is unlikely that the e^+e^- decays of the known vector mesons (ρ, ω, ϕ) are responsible for the observed "direct" electron production. At present, the source of these electrons is quite unclear. Phase III, with a factor of 100 in sensitivity, should be an important factor in resolving this question.

Figure 5 - The charge-averaged invariant cross-section plotted as a function of the center-of-mass momentum p_T^* . Also given for comparison is the British-Scandinavian fit to their measurement of the charge-averaged invariant pion cross-section, multiplied by a factor 10^{-4} .

IV. RESEARCH PROGRAM AT BNL:

The primary objective of the neutrino experiment is the study of the exclusive reactions

$$\nu + N \rightarrow \mu^- + p + \pi^0 \quad (2)$$

$$\nu + N \rightarrow \nu + N' + \pi^0 \quad (3)$$

Reaction (3) is due to weak neutral currents and the ratio of the cross section for (3) to that for (2) is a very important parameter that can be used to differentiate among the various gauge theories that require the presence of neutral currents.

The apparatus, a 30 ton spark chamber and scintillation counter detector, was completed by early 1974 and in a run with neutrinos in the spring of 1974, we obtained 300,000 pictures. These pictures have now been scanned and yielded 8,000 neutrino events. Among these, there are about 400 events due to reaction (2) and a number of events that are attributed to reaction (3). Presently we are studying the mass distribution of the π^0 -nucleon in the final state and the angular correlations. A paper will soon be prepared for publication.

We have requested from BNL and received approval for two more runs, one with neutrinos to improve our statistics and the other with antineutrinos. We intend to double the statistics of our neutrino sample and to obtain about the same number of pictures with antineutrinos as with neutrinos. The antineutrino run is very important because (a) theoretically, it provides us with more checks on the gauge theories and (b) experimentally, it is conducted under inherently different background conditions. We expect to have these runs completed by June 1975 and the scanning and measuring by early 1976.

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