COMMENTS ON THE IMPORTANCE AND FEASIBILITY OF EXPERIMENTS ON THE REACTION $\bar{p} + p \rightarrow \pi^+ + \pi^-$, ETC., UP TO 50 GeV/c

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ABSTRACT

It is important to study the reaction $\bar{p}p \rightarrow \pi^+\pi^-$ and other annihilation reactions producing dimeson final states, in the momentum region 10-50 GeV/c, since such reactions are related to $\pi^\pm p$ backward scattering by crossing symmetry. Estimates of rates are presented. Comments, but no detailed designs, are given on methods to do these experiments.

I. INTRODUCTION

No one has discussed the obvious desirability of using the anticipated flux of antiprotons at NAL to extend our knowledge of reactions such as $\bar{p}p \rightarrow \pi^+\pi^-$ into the higher energy region. These reactions are related by crossing symmetry to $\pi^\pm p$ backward scattering and can be very sensitive tests of particular Regge models in the intermediate energy region. The reaction kinematics, cross sections, and experimental difficulties are virtually identical to those of backward $\pi^\pm p$ scattering, except that antiprotons are more expensive than pions. Therefore, more efficient utilization of the antiprotons is warranted, i.e., more expensive detection apparatus which uses more of the reaction solid angle.

II. THEORETICAL IMPORTANCE

In the truly asymptotic region, in which all rest masses are small compared with the center-of-mass energy, and in which s-channel resonances are unimportant compared with exchange mechanisms, the reaction $\bar{p}p \rightarrow \pi^+\pi^-$ is related to the reaction $\pi^+p \rightarrow p\pi^+$ by:

$$\left(\frac{d\sigma}{du}\right)_{\bar{p}p} = \frac{1}{2}\left(\frac{d\sigma}{du}\right)_{\pi^+p} \quad \text{(at the same s and u)}.$$

The same is true if one replaces the π by a K. This result is purported to be quite general and model independent. If one guesses that cross sections are no more than

10% different from asymptotic when the center-of-mass energy is 10 GeV, then laboratory energies less than 50 GeV (corresponding to c.m. energy below 10 GeV) can be called "intermediate" energies. In this region, one needs a particular model to relate the crossed-channel amplitudes. The model most in vogue at the moment is the Regge model, or variations thereupon. This model has so many free parameters--namely, the couplings of allowable trajectories to the particles and the residue functions for the trajectories--that one needs to study as many related reactions as possible to provide a crucial test of the theory.

The relationship between $\pi^{\pm}p$ backward scattering and the related $\bar{p}p$ annihilation process has been worked out in a usable fashion by Barger and Cline,[1] in terms of unknown amplitudes for the allowable trajectories. These amplitudes contain an unknown residue function and a questionable shape which at the moment is merely assumed to be that obtained from an extrapolation of the spin-mass-squared plot of the particles, assumed to lie on the trajectory.

Whatever these unknowns might be, they are the same in the crossed-channel reactions. However, the different reaction kinematics pick out different sums and differences of these amplitudes, in such a way that the crossed-channel reaction is sometimes a more sensitive test of the form of the amplitudes than the differential cross section of a single reaction. As an example of this sensitivity, the ratio of the differential cross sections for the reactions $\bar{p}p \rightarrow K^+K^-$ and $K^+p \rightarrow pK^+$ can differ by as much as a factor of five, depending upon the assumed form of the $\Lambda_\alpha, \Lambda_\gamma$ pole, at 2 GeV/c laboratory momentum.[2]

Calculations with the same model of Barger and Cline also show that the guess of 50 GeV/c laboratory momentum as the start of the asymptotic region is not a bad guess. It is safe to assume that whatever the theory in vogue in 1972 might be, it will need tests in the 20-50 GeV region. It is highly probable that Brookhaven will explore the region up to 15 GeV and Serpukhov up to 25 GeV. At the moment there are some sparse data at 8 GeV/c and more plentiful data at 2.5 GeV/c.

III. DATA COLLECTION RATES

Extrapolations of present data indicate a differential cross section of magnitude 0.1 to 0.01 μb/sr for this reaction in the 20-50 GeV region, or a total cross section of 0.01 to 0.001 μb, the lower numbers applying to 50 GeV, the higher to 20 GeV. (Total cross section means here the total for the reaction $\bar{p}p \rightarrow \pi^-\pi^+$ with π^- forward, or with π^+ forward. It is presumed that both reactions are governed by the appropriate Reggeized exchange and are therefore peaked forward.)

As an indication of the data collection rate, let us consider doing the experiment at 50 GeV with the expensive very high intensity separated beam discussed elsewhere in this summer study.[3] This beam produces 5×10^5 antiprotons/pulse at 50 GeV. With a cross section of 0.001 μb and a 2 meter LH2 target, it takes 25 days to gather 1000 events, assuming 100% detection efficiency. At 20 GeV, there is a gain of a factor of 10 in cross section and a gain of a factor of 10 in beam intensity, so the experiment takes a mere half day or less. This large variation suggests that one should really design different experiments at the two extreme energies. At the lower energy, one can do a meaningful experiment with a more conventional beam, such as that designed by Foelsche,[4] and can use a simple detection apparatus which detects only 1/10 of the solid angle, such as that designed by D. White.[5] At 50 GeV, one must design an experiment which catches nearly all of the solid angle of the reaction.

IV. EXPERIMENTAL METHOD

As mentioned before, the reaction kinematics are nearly the same as those for backward $\pi^{\pm}p$ scattering. At 50 GeV, one expects the cross section to have fallen to 1/e of its maximum value at a center-of-mass angle of 4°, or about 0.4° in the lab. If one uses purely a forward, single-arm spectrometer detector, then one needs accuracies of the order of 0.06% in the momentum and 1/3 mrad in the direction of the forward π. Such accuracies are well within the grasp of present technology. At the higher momenta, at which the antiproton flux is small, this is a feasible approach, since the non-interacting antiprotons entering the spectrometer will not jam the various counters. This spectrometer easily catches nearly all of the reaction solid angle, since the differential cross section will probably have fallen to 1/e of its maximum value at 0.4° in the lab. A single-arm spectrometer experiment has the obvious bonus that one unavoidably studies many reactions, i.e., $\bar{p}p \rightarrow \pi^{+}$ + missing mass. The technique was successful at 8 and 16 GeV/c.[6]

On the other hand, one might need to go to some kind of double-arm spectrometer if the background under these small cross sections is too high, or if the forward spectrometer is too expensive, or if one wants to work with much higher beam fluxes. D. White[5] has designed one such spectrometer, but it loses much of the expected forward peak. A double-arm spectrometer such as suggested (and used) by Krisch[7] is very limited to the region close to 180°. (Note that at 50 GeV/c $\bar{p}$ momentum, a backwards π at an angle of 176° in the center-of-mass comes out at an angle of 142° in the lab.) It is difficult to detect a large solid angle with this type of spectrometer. Given the large expense of a separated $\bar{p}$ beam, it would seem foolish to examine the reaction only very near 180°.

I have not attempted a more detailed design at this time owing to lack of time and my own inexperience with this type of experimental work.

REFERENCES

[1] V. Barger and D. Cline, Phys. Letters 25B, 415 (1967).

[2] C. T. Murphy, unpublished.

[3] C. T. Murphy, Sketch of a Very High Flux Separated Antiproton Beam, National Accelerator Laboratory 1969 Summer Study Report SS-158, Vol. I.

[4] H. Foelsche, RF Separated Beam of Long Duty Cycle, National Accelerator Laboratory 1969 Summer Study Report SS-26, Vol. I.

[5] D. H. White, An Experiment to Look at Backward Peaks in π - p Scattering, National Accelerator Laboratory 1968 Summer Study Report C.1-68-11, Vol. III, p. 69.

[6] D. Birnbaum et al., Phys. Rev. Letters 23, 436 (1969). The authors did not report a result at 16 GeV/c. However, they took some data but found no signal, both because of the low $\overline{p}$ flux and the presumably small cross section.

[7] A. D. Krisch, Remarks on π - p Backward-Scattering Experiments, National Accelerator Laboratory 1968 Summer Study Report C.1-68-70, Vol. III, p. 83.