# Study of Anti-Neutron Annihilations at Low Energy*

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The motivation for the study of the anti-nucleon cross section at low energy has been discussed extensively at this conference and elsewhere.[1] Despite a substantial experimental effort a number of important questions have yet to be answered. Among them are:

a) At what energy does the $\bar{N}N$ interaction proceed exclusively through s-wave? What is the range of annihilation forces?

b) Are there important meson resonances produced in the direct channel of $\bar{N}N$ system above $\bar{N}N$ threshold?

A major obstacle in the study of $\bar{p}N$ at low energies is the energy loss of the antiproton due to ionization. This severely limits the track length which can be obtained at a given momentum. Furthermore, the rapid change in energy and the accompanying fluctuations in energy loss make it difficult to ascertain the energy of a particular interaction. One way to circumvent this problem is to "turn off" the energy loss mechanism by using anti-neutrons instead of antiprotons. The antineutrons can be obtained either directly in p-nucleus collisions or indirectly by first isolating antiprotons and allowing them to charge exchange ($\bar{p}p \to \bar{n}n$). The latter method has been used by our group at Wisconsin to study $\bar{n}p$ using both bubble chamber and counter techniques.

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V. Scherer, D. Cline and myself have studied interactions of antineutrons in the BNL 30" hydrogen bubble chamber which has since been retired.[2] In a 200,000 picture exposure of the chamber to a antiproton beam of variable momentum (500-750 MeV/c) we found 65,000 neutral "zero-prong" interactions. Of these about 2000 were accompanied by an $\bar{n}$ annihilation into three or more charged particles. In the bubble chamber the likelihood of observing a zero-prong and an annihilation is proportional to the production of the antiproton charge exchange cross section and the antineutron total cross section. Thus the charge exchange (CEX) cross section is obtained as a by-product in the analysis. The CEX results are shown in Fig. 1 which indicate that the charge exchange reaction remains a significant part of the $\bar{p}$ total cross section to energies quite near threshold (100 MeV/c). We measure the $\bar{p}$ momentum and the $\bar{n}$ laboratory angle only. Thus there is a two-fold ambiguity in the cm angle and consequently in the $\bar{n}$ laboratory momentum. Fortunately in a small number of events the ambiguity can be resolved by also observing the elastic scattering of the neutron. The forward backward ratio for the charge exchange reaction is shown in Fig. 2. Because the low energy antineutrons are correlated with backward angles, the approach to fore aft symmetry indicates the utility of the charge exchange technique in producing low energy antineutrons.

During the analysis of this experiment we became convinced that the technique of producing antineutrons coupled with a counter detector would be very useful in the investigation of the characteristics of annihilation at low energy. A pioneering experiment to measure $\bar{n}p$ total cross section was proposed at ANL in collaboration with J. Learned, J. Mapp, B. Gunderson and U. Camerini.[3] A diagram of the apparatus is shown in Fig. 3.

An enriched antiproton beam was produced by the Low Energy Separated Beam at ANL (Beam 42). This beam incorporated a single stage of electrostatic separation. The resultant beam had a $(\pi-\mu)/\bar{p}$ ratio of 50, as shown in Fig. 4 where the time of flight spectrum of the beam particles is shown. The use of time of flight rejection in the trigger coincidence and a water cerenkov counter (see Fig. 3) to reject light particles reduced the $\pi$-$\mu$ background in the trigger to $\sim$2%. An a posteriori cut on time of flight further reduced the background to a negligible value (Fig. 4). However, the rate of unwanted particles through the various counters was the limiting factor in the extension of the experiment to very low energies.

The identified antiprotons were directed into a polyethylene target in which counters $S_{1-3}$ were imbedded. The production of an antineutron was signaled by the disappearance of an antiproton with no count in the lead scintillator counter A. The detector was composed of five layers of steel and scintillator (about 1. absorption length). The momentum of the $\bar{n}$ is calculated from the time of flight between $T_2$ and the detector.

The measurement of the cross section is made by measuring the transmission of the antineutrons in poor geometry through a target. This target consisted of a $CH_2$ heptane liquid scintillator or an equal amount of Carbon in solid form. The hydrogen cross section can be obtained using the customary subtraction technique.

The "poor geometry" transmission measurement will provide only the inelastic cross section. However, information on the elastic scattering can be obtained from the active heptane target. Recoil protons from $\bar{n}$ elastic scattering on free hydrogen are stopped and the energy is measured by recording the pulse height of several 5" photomultipliers which view the scintillator. Coherent elastic scattering on the Carbon nucleous can be eliminated by its very small energy deposition. Incoherent elastic scattering is believed negligible because in a similar situation we measure less than five percent of the charge exchange antineutron production to occur on heavy nuclei.[4] Thus the pulse height distribution is proportional to the proton kinetic energy distribution which in turn is proportional to the momentum transfer t. In Fig. 5 we plot the t distribution measured in this way for all the data (250 to 750 MeV/c). The solid line is the measured slope from $\bar{p}p$ elastic scattering. The agreement is qualitative but suggests that we can correct the inelastic cross section using the elastic cross section and obtain the total cross section.

The results of the measurement of $\bar{n}$ total cross section are plotted in Fig. 6 together with other existing data. The dashed line is a parameterization of the $\bar{p}p$ total cross section by Kalogeropoulos.[5] The results indicate that the annihilation amplitudes are predominately I = 1 at low energy. The solid line represents the s-wave unitarity limit and the data support the conclusion drawn from $\bar{p}p$ data that even at the lowest momenta P-wave and higher are very important.

In conclusion, we have demonstrated that the technique of using antineutrons to study very low energy antinucleon interactions is feasible. The limitations of the experiment were imposed by the beam background rates and are not inherent in the method. The limitations of the bubble chamber experiment were imposed by the small size of the chamber which reduces the rate and introduces systematic errors in correcting for detection efficiency. We have addressed this problem by a very recent exposure of the ANL 12' bubble chamber to a low energy $\bar{p}$ beam. We expect to make a much more precise measurement using this excellent research tool.

## References


1. J. Rosner, L. Montanet and others at this conference. Also see J. Lamko, "Proton Antiproton Scattering Near Threshold", University of Chicago thesis.
2. V. Scherer, Ph.D. thesis, University of Wisconsin (1974).
3. B. Gunderson, Ph.D. thesis, University of Wisconsin (1975).
4. A more detailed study of the contribution of quasielastic scattering is in progress using an exposure of the ANL 40" propane chamber to low energy antiprotons.
5. T. Kalogeropoulos, "Direct Channel $\bar{N}N$ Phenomena", Proceedings of the Seminar on Interactions of High Energy Particles with Nuclei and New Nuclear-Like Systems, Moscow, ITEP, 1973.


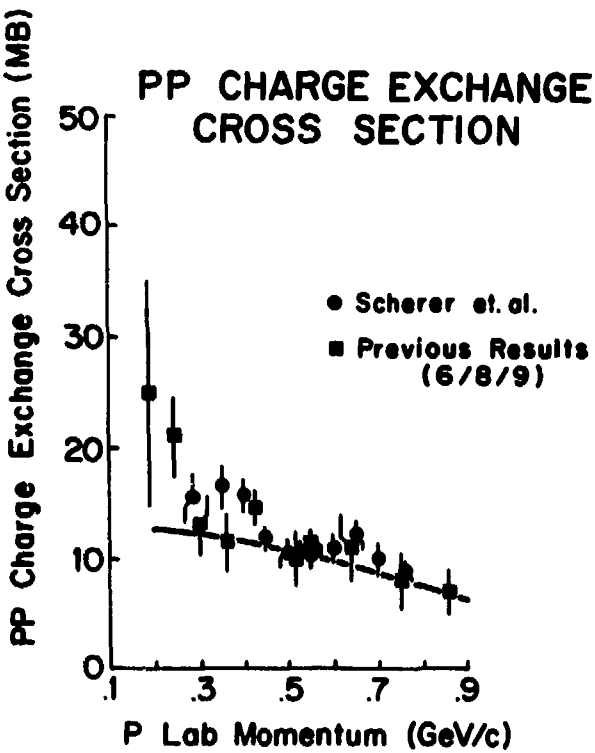


FIGURE 1

## ANTI-NEUTRON CROSS-SECTION MEASUREMENT

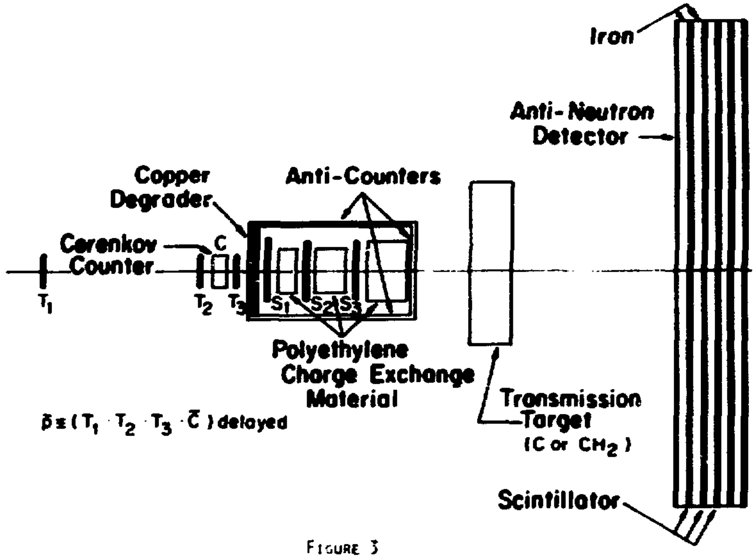


FIGURE 3

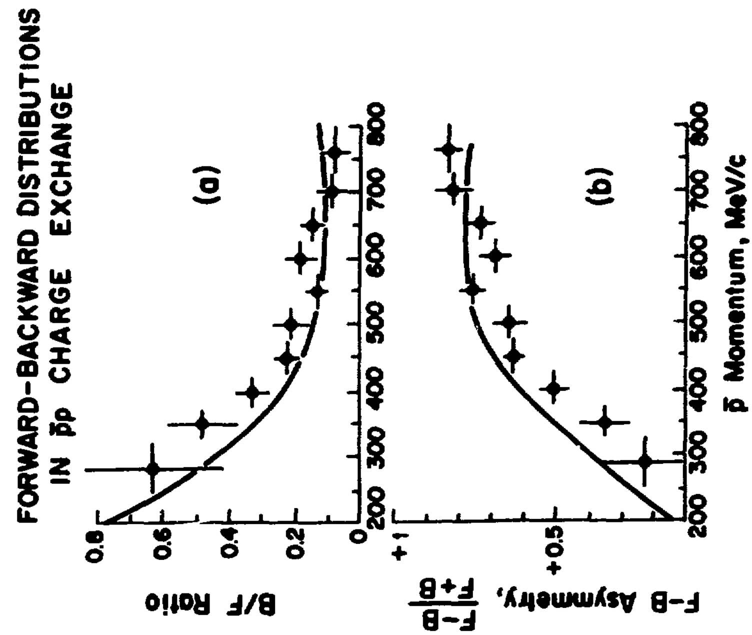


FIGURE 2

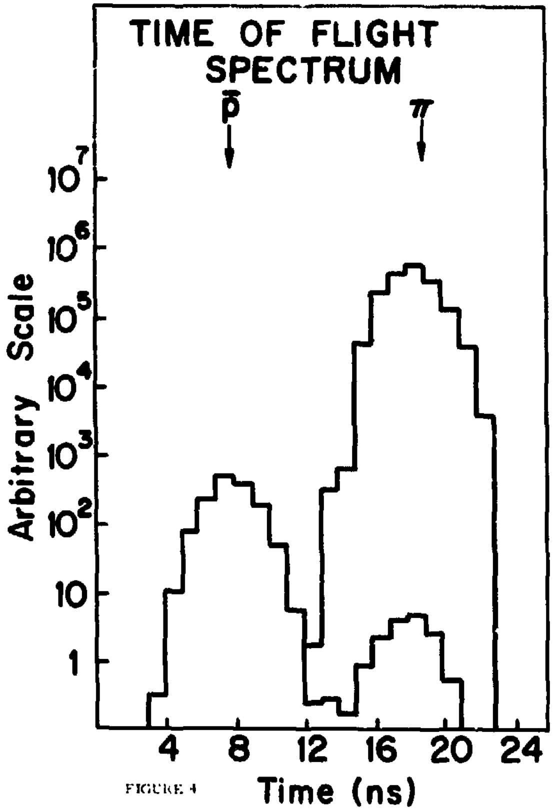


FIGURE 4

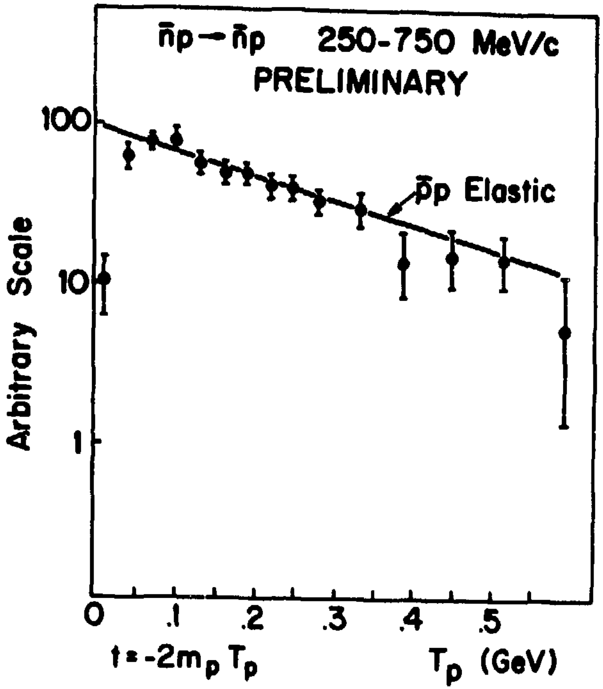


FIGURE 5

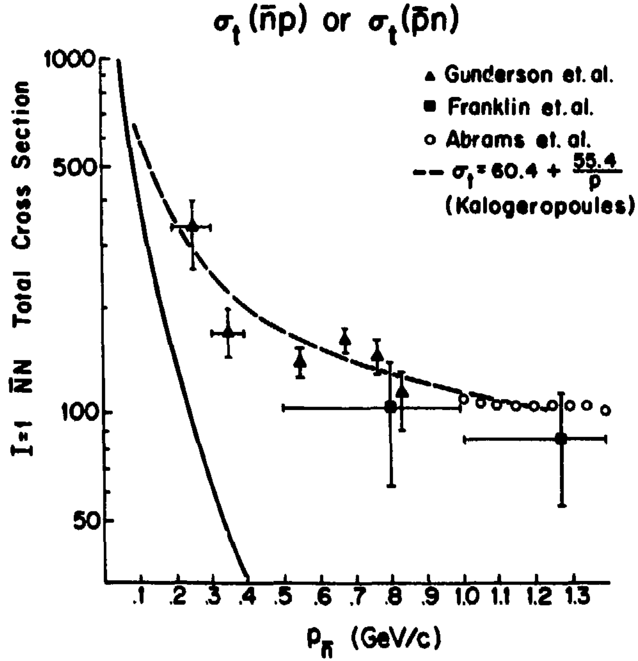
σt (n̄p) or σt (p̄n)
I=1 N̄N Total Cross Section
1000
500
100
50
▲ Gunderson et. al.
■ Franklin et. al.
○ Abrams et. al.
-- σt = 60.4 + 55.4/p
(Kalogeropoules)
.1 .2 .3 .4 .5 .6 .7 .8 .9 1.0 1.1 1.2 1.3
pn̄ (GeV/c)

FIGURE 6