CERN/PSCC/80-26
PSCC/I24
March 17, 1980

LETTER OF INTEREST

CERN BIBLIOTHEQUE

STUDY OF THE ANTIPROTON CHARGE EXCHANGE REACTION AND ANTINEUTRON INTERACTIONS AT LOW ENERGIES

H. Poth

Institut für Kernphysik, Kernforschungszentrum Karlsruhe
and
Institut für Experimentelle Kernphysik, Universität Karlsruhe

CERN LIBRARIES, GENEVA
CM-P00044731

INTRODUCTION

The expected antiproton beams at LEAR offer the possibility to study the antiproton charge exchange reaction $\bar{p}p \rightarrow \bar{n}n$ at low energy with high precision. The threshold for this reaction is at 98.7 MeV/c. At present total charge exchange cross section measurements are only available down to 276 MeV/c. Below 600 MeV/c the differential cross section is measured only at two energies. With $\bar{p}$-beams of LEAR the measurements can be extended practically to the reaction threshold. A considerable improvement in resolution and a high level of precision can be achieved for energies where data already exist.

The study of the charge exchange reaction is attractive for various reasons and had been pionted out elsewhere[1]. Besides the interest in the process itself, this reaction is the most powerful source for the production of antineutrons. The interaction of antineutrons with nucleons at low energies is experimentally hardly known.

KINEMATICS

The reaction is characterized by its simple two body final state, which differs from the elastic scattering kinematics only because of the antiproton-antineutron mass difference. This creates however an ambiguity in the relation between the momentum of the antineutron and its production angle in the laboratory frame. Moreover the conservation of the CM-momentum leads to a confinement of the antineutron production to small forward angles near the threshold (Fig.1). This is of great interest for the investigation of the threshold behaviour of the reaction cross section.

Measurements can be done on an external hydrogen target or on an internal gas jet target depending on the experimental goal and the required accuracy.

INTERNAL JET TARGET

High precision can practically only be achieved with an internal target. Furthermore the piont-like target and the omission of secondary interactions in the target renders the reconstruction of the interaction vertex and scattering corrections unnecessary which facilitates differential cross section measurements considerably. High energy resolution is required to resolve fine-structures of eventual narrow resonances (e.g. S-meson) and to improve the peak-to-background ratio of weak signals in cross section measurements. A high momentum resolution is also needed to approach the charge exchange threshold. The behavior of the cross section close to threshold reveals basic information on the $\bar{n}$ n interaction. For instance a production of the $\bar{n}$ n system in a s-state would strongly suppress the cross section owing to the rapid annihilation of the antineutron with neutron. The study of the threshold behavior profits very much from the particular kinematics since the full CM-solid angle is confined to a forward solid angle of 0.8 % in the laboratory frame below 100 MeV/c. The transformation from the CM- to the laboratory system and the exchange of pions in the t-channel enhance the forward production also at higher energies. This necessitates the access to forward angles, which is possible if a jet target is installed in the center of a bending magnet$^{2)}$ where the antineutrons can be extracted tangentially.

Already the operation of LEAR at 100 MeV/c without internal target requires a good vacuum and an effective cooling, if a long extraction time is needed. The installation of a jet target imposes even more stringent conditions for the cooling system to prevent a rapid blow up and loss of the beam and to conserve its momentum resolution. Below the transfer energy electron cooling can be applied. A stochastic precooling at the transfer energy would speed up the cooling even more.

The admissible jet target density is conditioned by the fact that the beam blow up time should be much smaller than the transverse electron cooling time. In this case beam losses can be reduced to single scatterings with angles larger than the acceptance at the position of the jet target. At low energies Coulomb scattering dominates and a gain of 9 and 36 in lifetime can be achieved if the acceptance angle is increased from 2.5 mrad to 7.5 mrad and 15 mrad respectively. The optimal count rates are achieved when the beam losses equal the accumulation rate of the antiprotons in the AA and the single scattering lifetime is longer than the time between refilling.

The following estimation of the tolerable target thickness, beam properties and count rates are based on the experience from electron cooling experiments in ICE$^{3)}$. At 300 MeV/c transverse cooling times between 2 - 3 sec were achieved and the single scattering limit was reached with a vacuum of 10^{-10} Torr (N_2). The equilibrium beam diameter and momentum spread was 1 - 2 mm and $\sim 10^{-4}$ for 10^8 stored particles. The ratio of single to multiple scattering lifetime was slightly below 10.

A similar performance for an electron cooling system in LEAR can be expected and in the following a transverse cooling time of 2 sec at 300 MeV/c, a ratio of ten between the two lifetimes and a rest vacuum of 10^{-11} Torr (N_2) is assumed. Under these assumptions a save estimate yields an admissible jet density of ρ_{jet} (300 MeV) = $2 \cdot 10^{-10}$ g/cm^2 resulting in a single scattering lifetime of about 700 sec for an acceptance of 2.5 mrad. During this time $7 \cdot 10^8$ antiprotons can be accumulated. The total strong interaction rate can be calculated with

$$R = N_o \cdot L \cdot \sigma \cdot \rho_{jet} \cdot f_{rev}$$

N_o : number of stored $\bar{p} = 7 \cdot 10^8$
L : Avogadro's number = $6 \cdot 10^{23}$
σ : total $\bar{p}$-cross section = 240mb(300Me
f_{rev} : revolution frequency = $1.2\ 10^6 s^{-1}$ "

The rates and allowed target densities can be estimated for other momenta using the known scaling for lifetimes $\tau \sim \beta^3\gamma^2$ (i.e. scaling for target thickness), transverse cooling times $\tau_\perp \sim \beta\gamma^2\, T_\perp^{3/2}/j_e$, cross section $\sigma \sim 1/\beta$ and revolution frequency $f_{rev} \sim \beta$. The charge exchange rate $R_{\bar{n}}$ is about 6.5% of the total strong interaction rate for most of the momenta below 600 MeV/c. Using these relations the allowed target densities and reaction rates are estimated for a constant perveance gun ($j_e \sim \beta^3\gamma^3/(\gamma+1)^{3/2}$), an acceptance of 2.5mrad and a single scattering beam life time of about 700 sec which are given in the following table ($7\cdot10^8$ stored $\bar{p}$).

Table I

$p_{\bar{p}}$ (MeV/c)	ρ_{jet}(g/cm^2)	R (sec^{-1})	$R_{\bar{n}}$ (sec^{-1})	$\sqrt{s}$ (KeV)
100	$8\cdot10^{-12}$	10^3	10^{+}	1
300	$2\cdot10^{-10}$	$2.5\cdot10^4$	1600	5
500	10^{-9}	$1.2\cdot10^5$	8000	20

+: σ_{cex}/σ = 1% assumed

The number of stored antiprotons and the target thickness is comfortable for cooling. Equivilibrium beam diameters of a few mm and a momentum spread close to 10^{-4} can be expected.

Although the count rates at 100 MeV/c are rather low, it should be remembered that the full CM-solid angle is confined to a forward cone in the lab. frame with an opening angle of less than ±10°. The expected CM-energy resolution demonstrates that this technique is perfectly suited to study narrow resonances and threshold effects. The latter can be investigated with a simple set-up consisting essentially of a small forward antineutron counter. The threshold is scanned by changing the momentum of the stored antiprotons within a few percent (range of LEAR acceptance) which can be done very precisely by changing the high voltage of the electron gun. A relative accuracy around 10^{-5} could be achieved.

It should be noted that the numbers in table I can be increased by a factor of 36 for an acceptance of 15 mrad at the position of the jet target.

EXTERNAL TARGET

Although experiments at an internal target can be done with high resolution short survey measurements of the total charge exchange cross section on an external target with a modest set-up may prepare more detailed studies. With a segmented hydrogen target the degradation of the resolution due to the unknown energy loss of the antiproton prior to the charge exchange reaction can be minimized and a $\sqrt{s}$ - resolution of a few MeV can be achieved. For total cross section measurements no positive identification of the $\bar{p}$ is needed. With a hydrogen target covered by a veto box for charged and neutral particles the charge exchange reaction can be detected by the disappearance of the antiproton in a target segment and no signal in the veto counters. Below 800 MeV/c only annihilation and elastic scattering are the allowed reaction modes beside the charge exchange. The expected count rates and energy resolutions for a target with a total density of $1 g/cm^2$ and slice thickness of $150 mg/cm^2$ are given in table II for 10^6 extracted $\bar{p}$ per sec.

Table II

momentum of extract. beam MeV/c	covered momentum region MeV/c	momentum resolut./bin %	resolut. in CM-energy MeV	total useful count rate sec^{-1}
300	300 - 0	5 - 15	2 - 5	12000
370	370 - 300	2	2	9000
420	420 - 370	2	1.5	8400
460	460 - 420	1.5	1	8100
490	490 - 460	1	1	8000
510	510 - 490	<1	<1	7800

Owing to the fact that in principle every charge exchange reaction can be detected, the count rates are high. It should be noted that with this experimental set-up the annihilation cross section can be determined simultanously.

The possibility of tagging the charge exchange reaction allows for the application of a particular method to measure the low energy antineutron annihilation cross section:

The absorption length of an antineutron in hydrogen is

$$\lambda = \frac{1}{L\ \sigma_{ann}\ \varrho}$$

L : Avogadro's number
ϱ : density of hydrogen
σ_{ann}: antineutron annihil. x-section

Hence the average time until annihilation occurs is

$$t = \frac{\lambda}{\beta \cdot c} = \frac{1}{L \cdot \varrho \cdot c \cdot \beta \sigma_{ann}}$$

βc : velocity of the antineutron

Owing to the 1/v behaviour of the cross section the product $\beta \cdot \sigma_{ann}$ is approximately constant at low energies. The corresponding value for the antiproton annihilation is $\beta \cdot \sigma_{ann} \cong 40$ mb. Hence by measuring the annihilation time, the annihilation cross section can be determined. With the above cross section an annihilation time of 96 ns is reckoned which is easily measured.

Low energy antineutrons could be produced through charge exchange at the entrance of a liquid hydrogen target. The range of 100 MeV/c antiprotons is 5 mm in liquid hydrogen. Adjusting the range curve to this value would select practically monoenergetic antineutrons of an energy around 1.3 MeV. They are produced in a small forward cone (Fig.1) and follow the direction of the beam. Having a velocity of $\beta = 0.05$ they would travel in average 1.5 m before they annihilate. The annihilation time can be measured from the time difference between the entrance of the antiproton and the appearance of the annihilation detected through the annihilation products. With an estimated charge exchange cross section of 10 mb at 100 MeV/c and an annihilation detection efficiency of 10 % a count rate of about 100 sec can be expected. The experimental set-up could be extremely modest consisting essentially of a beam scintillator, a long liquid hydrogen target and an annihilation-counter. Electronics would be unsophisticated, a TAC and Multichannel analyzer would be sufficient. The described experiments are preferentially done on a external target because they require the tagging of the antiproton charge exchange reaction.

CONCLUSION

It has been pointed out that the operation of an internal target is a necessary prerequisite for high resolution measurements of the antiproton charge exchange cross section close to threshold and in resonance regions. The operation of an internal target below the transfer energy is enabled by the application of electron cooling. Electron cooling can work continuosly at all desired energies below 600 MeV/c and provide fast enough cooling times to tolerate a reasonably thick internal target. The admissible target densities are well in the range of the present technology$^{4)}$ and count rates are comfortably high. The internal target has to be installed in the center of a bending magnet as proposed earlier$^{2)}$ to enable access to the forward angles and to increase the antiproton beam acceptance. It has been emphasized that with modest experimental means the threshold behaviour of the charge exchange cross section can be investigated with high resolution. Count rates are still acceptable owing to the particular kinematics. It has been outlined that a survey measurement of the total charge exhange cross section and a determination of the low energy antineutron annihilation cross section can be made with a simple experimental set-up.

A collaboration with the PS and EP Division for the developement of an electron gun has been set up some time ago and a first concept has been worked out. For the construction of an internal target contacts have been established and discussions are underway. Moreover we intend a further extension of our engagement in both activities in the near future.

The aim of this letter is furthermore to point out some experimental possibilities opened by such installations and to state the interest in experiments as described above. However no firm commitments concerning the performance of these experiments can be made at present.

REFERENCES

1) J. C. Kluyver, LEAR Note 06
H. Poth, LEAR Note 15
C. Voci, LEAR Note 20
H. Poth, LEAR Note 51
C. Voci, LEAR Note 71

2) K. Kilian, CERN/PSCC/80-8, PSCC/M47, Jan. 80

3) M. Bell, J. Chaney, S. Cittolin, H. Herr, H. Koziol, F. Krienen, G. Lebée, P. Møller Petersen, G. Petrucci, H. Poth, T. Sherwood, G. Stefanini, C. Taylor, L. Tecchio, C. Rubbia, S. Van der Meer and T. Wikberg, Phys. Lett. 87B, 275 (1979)

4) W. Kubischta, LEAR Note 17
W. Obert, LEAR Note 43
O. Hagena, private communications

ANTINEUTRON ANGULAR DISTRIBUTION FOR THE CHARGE EXCHANGE REACTION

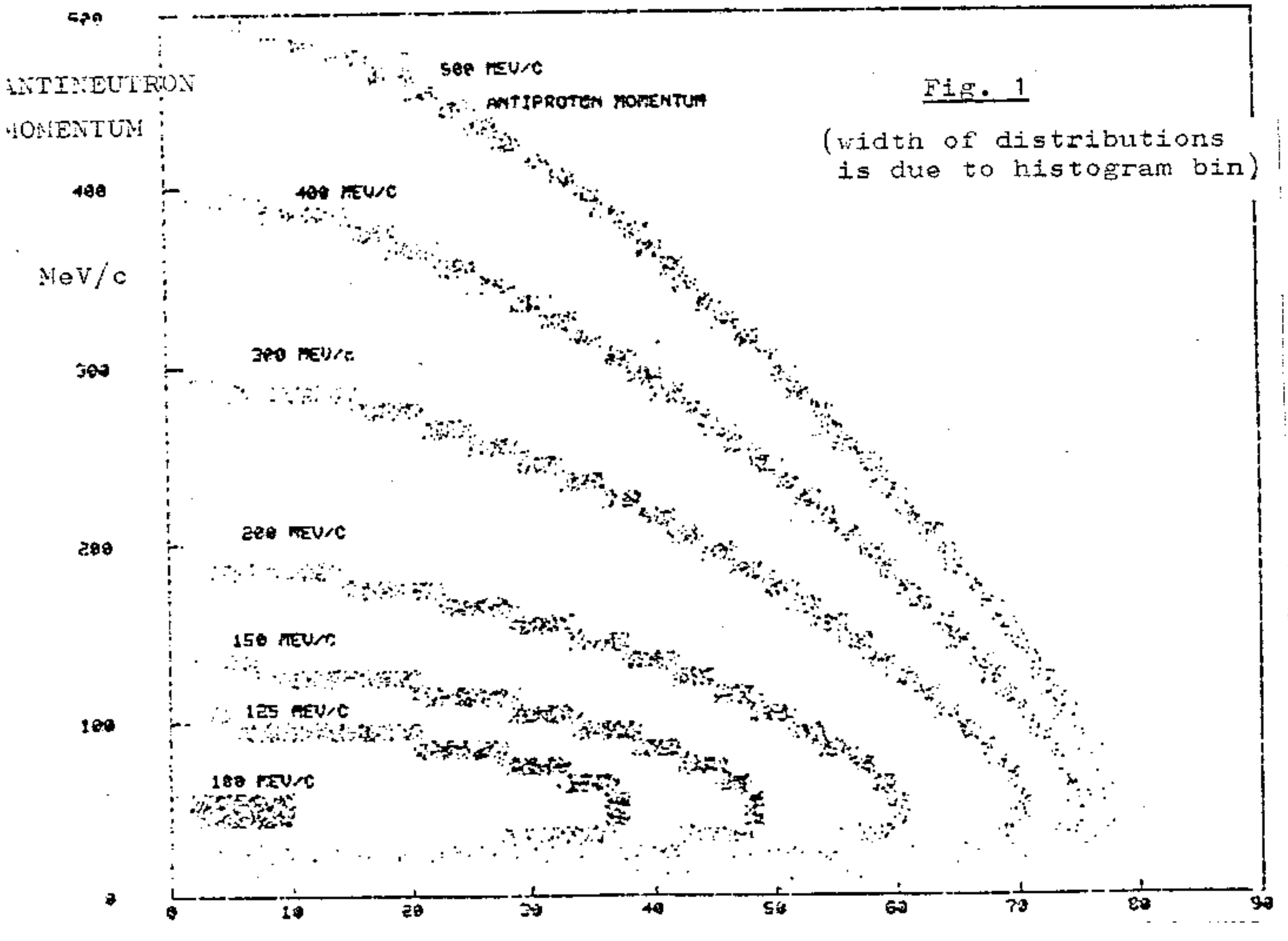

Fig. 1

(width of distributions
is due to histogram bin)