LA-UR -85-1481

CONF-8503120--6

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36.

LA-UR--85-1481

DE85 010729

TITLE: ANTIPROTON ANNIHILATIONS IN NUCLEI

AUTHOR(S): P. . McGaughey, K. D. Bol, M. R. Clover, R. M. DeVries, M. J. DiGiacomo, J. S. Kapustinsky, G. R. Smith,* J. W. Sunier, W. E. Sondheim, and Y. Yariv,** Los Alamos National Laboratory, Los Alamos, NM 87545
M. Buenerd, J. Chauvin, D. Lebrun, and P. Martin, Institut des Sciences Nucléaires, 38026 Grenoble, Cedex, France
J. C. Dousse, Université de Fribourg, 1700 Fribourg, Switzerland

SUBMITTED TO: AIP Conference Proceedings, Meeting at Tempe, AZ, March 10-14, 1985

MASTER

Permanent addresses: *TRIUMF, Vancouver V6T 2A3, British Columbia.
**Soreq Nuclear Research Center, Yavne 70600, Israel.

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

FORM NO 836 R4
ST NO 2629 5/81

ANTIPROTON ANNIHILATIONS IN NUCLEI

P. L. McGaughey, K. D. Bol, M. R. Clover, R. M. DeVries,
N. J. DiGiacomo, J. S. Kapustinsky, G. R. Smith,* J. W. Sunier,
W. E. Sondheim, and Y. Yariv**
Physics Division, Los Alamos National Laboratory,
Los Alamos, NM 87545

M. Buenerd, J. Chauvin, D. Lebrun, and P. Martin
Institut des Sciences Nucléaires, 38026 Grenoble, Cedex, France

J. C. Dousse
Université de Fribourg, 1700 Fribourg, Switzerland

ABSTRACT

Recent results from LEAR experiment PS187 are presented. Preliminary data for the inclusive production of π^+, K^+, and p from the annihilation of 180 MeV antiprotons in ^{28}Si and ^{238}U are compared with predictions of intranuclear cascade calculations. Proton and pion production data are well reproduced by the calculations, but kaon yields at low momenta appear to be strongly suppressed in the experimental data.

INTRODUCTION

One of the primary goals of LEAR experiment PS187 is to measure the features of light charged particle ($\pi^{\pm}$, $K^{\pm}$, p, d and t) production following the annihilation of antiprotons on a variety of nuclei. This study of the inclusive spectra is aimed at determining whether or not anything unusual (above and beyond the known $\bar{p}$-N, π-N, Δ-N and N-N interactions) takes place in $\bar{p}$-nucleus annihilations. In particular, the study of the K^+ spectra is of interest, since these kaons are produced only in the annihilation process and should travel relatively undisturbed through the nuclear medium, due to the small K^+-N interaction cross sections. Thus, the K^+ may carry cleaner information on the annihilation process inside nuclei than is the case with pions. These data are to be compared to the predictions of Monte Carlo Intra Nuclear Cascade (INC) calculations[1,2] which provide a quantitative simulation of the conventional physics expected from low energy antiproton annihilations in nuclei.

EXPERIMENTAL ARRANGEMENT

A broad range spectrometer, depicted in Fig. 1, was developed for the experiment, and tested at LAMPF and TRIUMF.[3,4] It consists of a circular dipole magnet, 81 cm in diameter, with a pole gap of

Permanent addresses: *TRIUMF, Vancouver V6T 2A3, British Columbia.
**Soreq Nuclear Research Center, Yavne 70600, Israel.

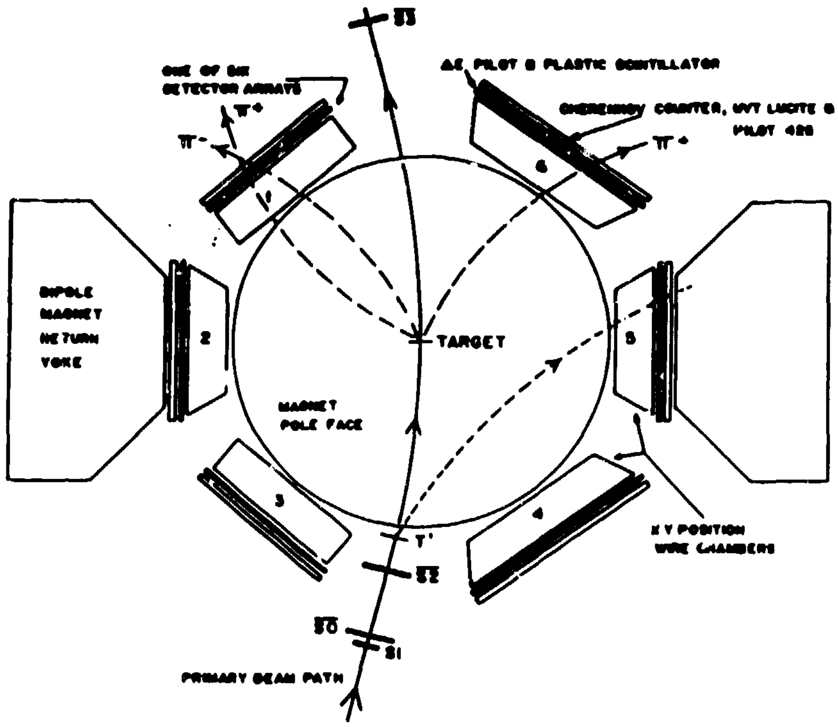

Fig. 1. Schematic diagram of CALLIOPE spectrometer.

12.7 cm and a magnetic field of 1.2 Tesla. Targets were placed in a vacuum chamber in the pole gap at the center of the magnet. Six detector modules consisting of a pair of x,y position sensitive gas counters, 10 cm apart from one another, together with a plastic scintillator (ΔE) and a plastic threshold Cherenkov detector[5] surround the pole gap. These detector modules provide position, time of flight, energy loss and Cherenkov information. Together with the momentum and scattering angle obtained from the reconstruction of the particle trajectories, they allow for the identification of π, K, p, d and t. The beam is counted by a thin scintillator (S1), and event triggers are defined by the combination $s_1 \cdot \bar{s}_2 \cdot \Delta E \cdot \bar{s}_3$. The electronics and data acquisition system are capable of acquiring data at a sustained rate of 1000 events per second, with minimal dead time. This spectrometer system provides angular acceptance of ~1/2 sr, angular coverage of $0^\circ < \theta_{lab} < 180^\circ$ and momentum acceptance of $0.1 < p_{lab} < 1.5$ GeV/c.

INTRA NUCLEAR CASCADE MODEL

In order to search for any "exotic" effects in the experimental data, a reliable calculation of the known physics is required. We have chosen to use the INC code of Clover et al.[1,2] which was developed to treat low energy antiproton-nucleus interactions. This computer code is a modified version of the INC code ISABEL written by Yariv and Fraenkel.[6,7] Annihilations were included by taking the experimental characteristics of nucleon-antinucleon annihilation and scattering and allowing the resulting particles to cascade through the nucleus in the conventional way. All of the known pion and kaon branches are included in the annihilation channels.

ACTIVE Si TARGET/DETECTOR

The use of an active target, like a Si detector, beside offering a clean way of scaling the beam on target and efficiently rejecting most of the background events, promises to allow selection of central annihilations. Using the results of the INC calculations, the total amount of charged particle energy deposited in the Si detector subsequent to an annihilation can be determined. This is performed by calculating the energy loss of each charged particle emitted from the nucleus as it propagates through the Si wafer. The computation includes the dE/dx from: the incident $\bar{p}$ up to the point of annihilation; $\pi^{\pm}$, $K^{\pm}$ and p emission from the INC calculation; p, d, t, ^{3}He, and α production from nuclear evaporation; and the recoil energy of the residual nucleus.

The result of this calculation indicates that in the cases in which a large Si pulse is obtained, most of the Si signal is due to cascade protons and evaporation particles, thereby reflecting the amount of excitation deposited in the nucleus by the annihilation process. This quantity in turn is quite sensitive to the depth at which the annihilation occurred inside the nucleus, since annihilations near the surface deposit the least amount of excitation energy in the nucleus. The correlation between the Si detector signal and the annihilation radius is shown in Fig. 2. It is apparent that by choosing events with greater than 80 MeV deposited in the Si detector (the dashed histogram), the annihilations which take place on the nuclear surface can be rejected and the resulting data set will contain events for which the mean annihilation radius is inside the half density nuclear surface.

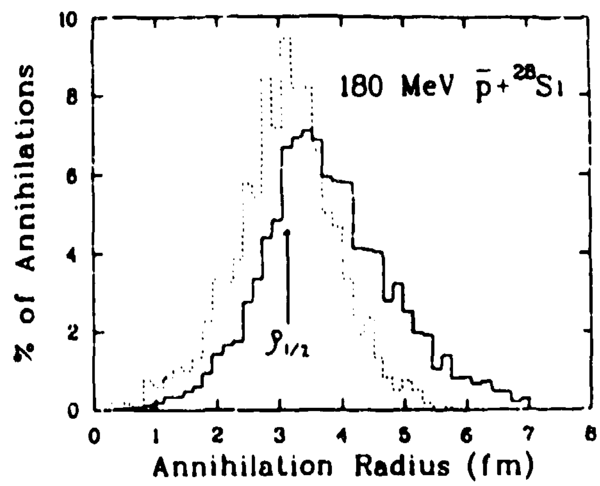

Fig. 2. Annihilation probability as a function of annihilation radius calculated using the INC model for the interaction of 180 MeV $\bar{p}$ + ^{28}Si. The solid histogram is for all events, while the dashed histogram is for events which deposited greater than 80 MeV in the Si detector.

EXPERIMENTAL RESULTS

In Fig. 3 the angle integrated momentum distributions are presented for π^{+} and p produced in the interaction of 180 MeV $\bar{p}$ with ^{28}Si and ^{238}U. The solid histograms are the experimental data, while the dashed lines represent the INC calculations. A striking feature is observed in the pion momentum distribution; the spectra show

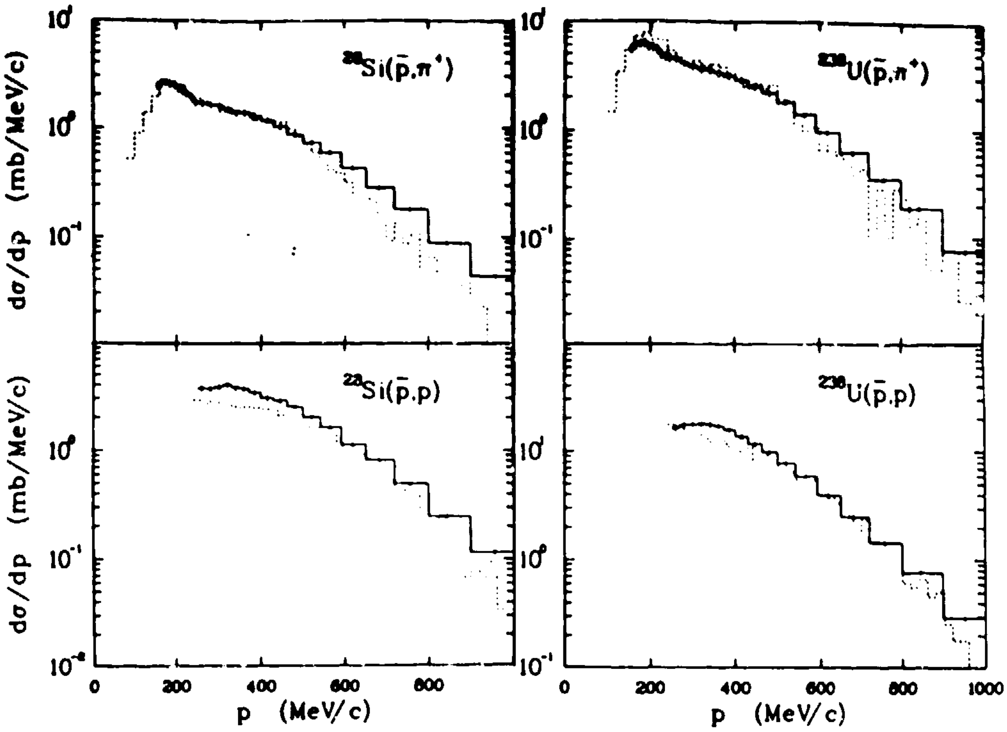

Fig. 3. Angle integrated momentum distributions for π^+ and p following the interaction of 150 MeV $\bar{p}$ with ^{28}Si and ^{238}U. The solid histograms are the experimental data while the dashed histograms are the result of INC calculations.

two bumps, one at high momentum which corresponds to primordial pions produced in the annihilation and another at low momentum which is presumably due to pions that formed deltas and reappeared at lower energies. This structure is well reproduced by the INC calculation for both target masses, with the exception of the fit at the highest pion momenta. The distributions from uranium and silicon show little difference other than the slopes at high momenta being steeper for uranium, which reflect the surface nature of the annihilation and the larger interaction probability for fast pions in uranium relative to silicon, respectively. Angular distributions of the pions (not shown here) show that the low energy pions are emitted isotropically from the targets, while the high energy ones appear to be coming from the rest frame of the nucleon-antinucleon system. These distributions are also well described by the INC results.

The proton momentum distributions are relatively featureless with a broad maximum at low momenta. The shape and magnitude of the distributions from Si and U are again well fit by the INC calculations which confirms the belief that the protons receive their kinetic energy primarily via the path of delta formation and absorption:

$$\pi + N \rightarrow \Delta \quad (1)$$

$$\Delta + N \rightarrow N + N \quad (2)$$

Little dependence of the shapes of these distributions upon target mass is observed other than the slope at high momenta again being steeper for uranium. Angular distributions of the protons are generally isotropic, which is consistent with the mechanism shown above and is well reproduced by the INC calculations.

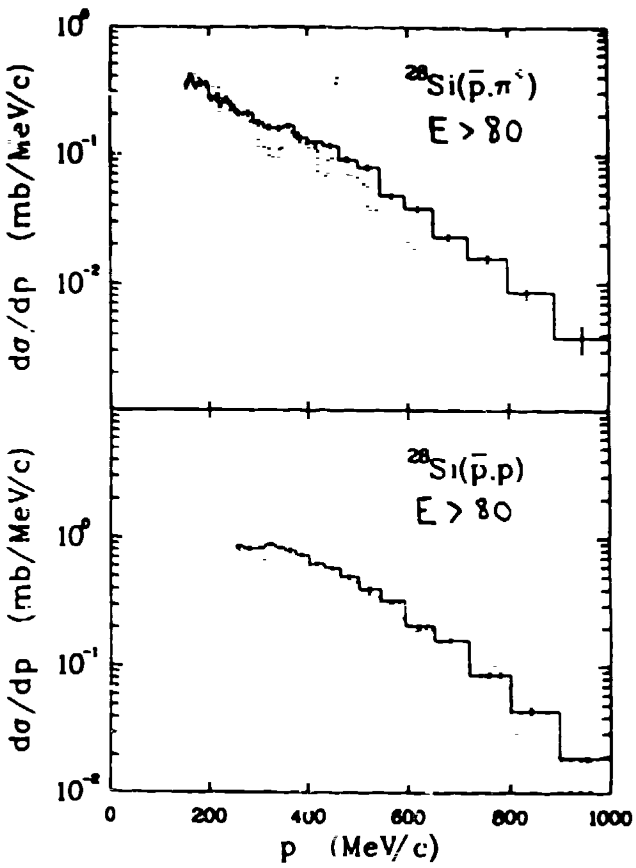

Fig. 4. Angle integrated momentum distributions for π^+ and p following the interaction of 180 MeV $\bar{p}$ with ^{28}Si, gated by an energy deposition of greater than 80 MeV in the Si detector. The solid histograms are the selected experimental data and the dashed histograms are the selected results of INC calculations.

In Fig. 4 the momentum distribution for π^+ and p from Si gated by a large signal (E > 80 MeV) in the Si detector are compared with the gated results from the INC model. The shapes of both experimental distributions are similar to the ungated data discussed previously but are depleted at high momenta and enhanced at low momenta. Thus the net effect of gating the silicon spectra to select smaller average annihilation radii is somewhat similar to choosing a heavier mass target, as has been observed for uranium. The INC model results fit the selected Si data to the same degree of accuracy obtained earlier for the unselected data. Nothing unexpected is observed in the spectra as a result of selecting annihilations that occur primarily inside the half density nuclear radius versus outside this radius for the ungated events.

Thus by considering only the experimental measurements for protons and pions, one would be forced to conclude that nothing unexpected is occurring in $\bar{p}$-nucleus annihilations. Most of the annihilations are taking place on the nuclear surface and once the annihilation occurs, the pions formed appear to interact primarily via the delta resonance pathway. However, the preliminary experimental kaon momentum distributions, shown in Fig. 5, are not consistent with the predictions of the INC model; the experimental data are ~4 times lower than the model calculations at ~200 MeV/c momentum. At much larger momenta the agreement is excellent. The shape of the experimental spectrum is even inconsistent with the shape of the known primordial kaon

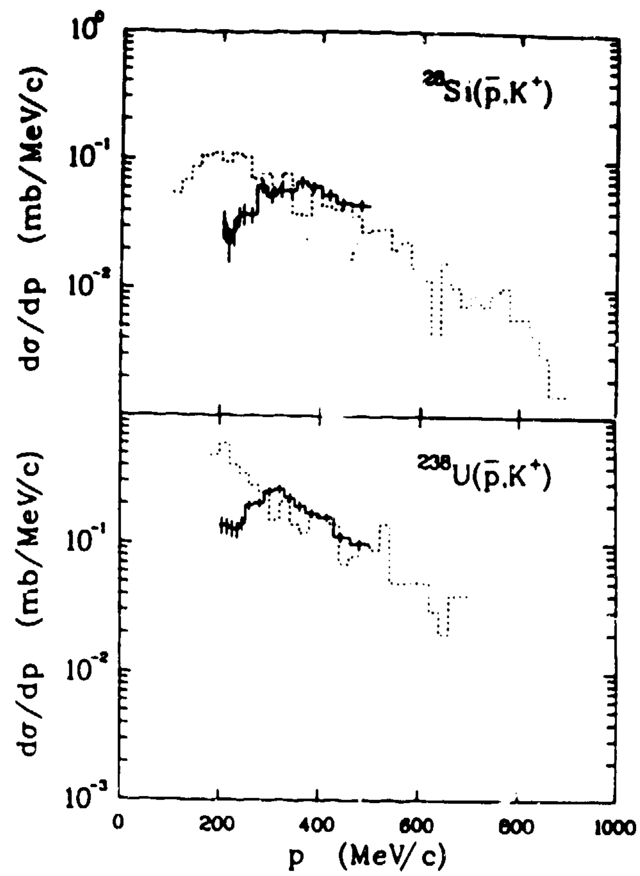

Fig. 5. Angle integrated momentum distributions for K^+ production from the interaction of 180 MeV $\bar{p}$ with ^{28}Si and ^{238}U. The solid histograms are the experimental data and the dashed histograms are the result of INC calculations.

distribution direct from the $\bar{p}$-N annihilation; there simply are too few low momentum kaons in the experimental data. This may be a signal that the kaon branches of the annihilation channel are strongly affected by the nuclear medium, perhaps due to a change in confinement scale as has been recently suggested[8] as the cause of the EMC effect. It was not possible to select the kaon events according to annihilation radius, using the Si detector pulse height, due to inadequate statistics.

CONCLUSIONS

Pion and proton production data from the interaction of 180 MeV $\bar{p}$ with ^{28}Si and ^{238}U are now available. In general, these experimental measurements are well reproduced by conventional Intra Nuclear Cascade calculations, even when annihilations believed to occur inside the half density nuclear radius are selected. Preliminary data for K^+ production are inconsistent with INC calculations and with free $\bar{p}$-N annihilation data. K^+ production appears to be suppressed for low momentum kaons produced in $\bar{p}$-nucleus annihilations.

REFERENCES

1. M. R. Clover, R. M. DeVries, N. J. DiGiacomo, and Y. Yariv, Phys. Rev. C26, 2138 (1982).
2. N. J. DiGiacomo and M. R. Clover, J. Phys. G10, L119 (1984).
3. N. J. DiGiacomo, M. R. Clover, R. M. DeVries, J. C. Dousse, J. S. Kapustinsky, P. L. McGaughey, W. E. Sondheim, J. W. Sunier, M. Buenerd, and D. Lebrun, Phys. Rev. C31, 292 (1985).
4. J. W. Sunier, et al., submitted to Nucl. Instr. Meth. (1985).

5. W. E. Sondheim, R. M. DeVries, M. R. Clover, N. J. DiGiacomo, J. S. Kapustinsky, and J. W. Sunier, Nucl. Instr. Meth. 219, 97 (1984).
6. Y. Yariv and Z. Fraenkel, Phys. Rev. C24, 488 (1981).
7. Y. Yariv and Z. Fraenkel, Phys. Rev. C20, 2227 (1979).
8. F. E. Close, R. L. Jaffe, R. G. Roberts, and G. Gross, Phys. Rev. D31, 1004 (1985).