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PROPOSAL FOR A STUDY OF PARTICLE EMISSION INDUCED IN THE ABSORPTION OF STOPPED π^- IN ^{16}O

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INTRODUCTION

The absorption of pions in nuclei has received considerable experimental and theoretical interest for many years because of its potential for obtaining nuclear structure information*).

Two kinds of experiments on pion absorption with particle emission have been carried out with π^- at rest and $\pi^\pm$ in flight with energies below 200 MeV preferentially in light nuclei . Experiments with nuclear emulsion and with bubble chambers have yielded information about the emission of charged particles into a solid angle of 4π, but obviously nothing can be learnt about the emission of neutrons . Counter experiments have produced information about neutrons as well as charged particles but are limited to certain geometries which prejudice the information to be gained. Most experiments of the latter kind have been concerned with the (π, 2N) process, the more recent ones being the $(\pi^+, 2p)$ measurements of Favier et al.2) on a large number of nuclei, the ^{6}Li $(\pi^+, 2p)$ measurement of Burman and Nordberg3), the $(\pi^-, 2n)$ experiments of Calligaris et al.4), Davis et al.5) and Cheshire and Sobottka6) and the $(\pi^-, 2n)$ and (π^-, np) measurements of Nordberg et al.7) on several nuclei. These measurements have yielded information about the excitation spectra of the residual nuclei (the best energy resolution has been E = 6 MeV), about the angular correlation between the emitted nucleon pairs, about the recoil momenta and the single

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*) A detailed review of this subject has been given recently by Koltun1).

nucleon energy spectra. This information, however, has been of limited value: for lack of statistical accuracy the data have been presented as a function of one variable only, integrating over the others in a geometry-dependent way. When integrating possible existing structure may be smeared out and the results will be different for each individual set-up.

This could explain some apparent discrepancies in some data, like: a factor of 750 between the $^{12}C(\pi^+,2p)$ cross-section as measured in a counter experiment$^{2)}$ and in a bubble chamber$^{8)}$, different excitation spectra in the same residual nuclei produced by $(\pi^-,2n)$ $^{6)}$ and $(\pi^+,2p)$ reactions$^{2)}$, and different single-nucleon spectra$^{9)}$ (observed in coincidence measurements) for the same nucleus. There is also little or no information about (π^-,np) $^{7,9)}$ and (π^+,np) reactions and scanty information about angular correlation of nn pairs$^{7)}$. The ratio $W(\pi^-,2n)$ / $W(\pi^-,np)$ is uncertain$^{9)}$. Little is known about processes like (π^-,nd) and $(\pi^-,nt)^{9,10)}$.

There are several theoretical approaches to describe the absorption of pions in nuclei but due to inherent conceptual difficulties the results from various calculations differ considerably.

The microscopic treatment$^{12)}$ of the pion absorption on two nucleons requires the knowledge of the following parts of the calculation: wavefunction of a pion in the nucleus, pion-nucleon interaction, rescattering, wave function of the nucleons including short-range behaviour, final-state interactions between the emitted nucleons and the interaction of these nucleons with the residual nucleus.

An alternate, semiphenomenological approach$^{1)}$ avoids the introduction of a short-range correlation function and reduces the uncertainties of using the (π,N) Hamiltonian in such a complicated process. It assumes the capture to proceed through the elementary reaction $\pi + 2N \rightleftarrows N + N$ for which experimental information exists$^{11)}$.

Besides the absorption by a nucleon pair, the absorption by an α cluster$^{13)}$ has been studied theoretically, but has not yet been tested in detail.

From a survey of the present experimental and theoretical situation we conclude that further experiments with greatly improved statistics, better energy resolution and reliable particle identification are certainly needed in order to provide better data and to stimulate further theoretical investigations. Such experiments are feasible with the improved SC.

PROPOSED EXPERIMENT

We propose to study the absorption of π^- at rest in ^{16}O, i.e. to measure the (π^-,nx) reactions where x can be n, p, d or t. ^{16}O was selected because a number of theoretical predictions on pion absorption exist for this nucleus. π^- at rest was chosen to avoid additional experimental and theoretical complications connected with the pions in flight.

The (π^-,nx) reactions will depend on 3 kinematical variables only, namely $|K_1|$, $|K_2|$ and θ. K_1, K_2 are the momenta of the outgoing particles, and θ their relative angle. We intend to study:

1) The excitation-energy spectrum of the $(\pi^-,2n)$ reaction for various ranges of the recoil momentum $\vec{p}_r = -(\vec{K}_1 + \vec{K}_2)$. These spectra should give information about two-hole states in the residual nucleus e.g. their position, decay width, spreading and relative strength. They will be compared with some theoretical predictions$^{12,14)}$, and with experimental data on other knock-out or direct particle-transfer reactions like (p,2p), (p,dp), (d,α) etc.

2) The distribution of recoil momenta for relevant parts (peaks) in the excitation-energy spectrum. This is related to the momentum sum of the absorbing nucleon pairs before the absorption, and can be compared with theoretical predictions$^{15,16)}$.

3) The energy sharing between the neutrons of a pair for fixed values of excitation energy. Theoretical predictions$^{16,17,18)}$ indicate that the distribution of the energy shared is sensitive to the short-range correlations and to final-state interactions of the nucleon pair.

4) A repetition of 1) to 3) for the reaction (π^-,np). In addition, the ratio $W(\pi^-,2n)/W(\pi^-,np)$ will be determined. The results will be compared with a series of theoretical calculations$^{12,17,18,19)}$.

5) The energy spectra of deuterons and tritons in coincidence with neutrons, the nd- and nt-angular correlations and the ratio $W(\pi^-,np)/W(\pi^-,nd)/W(\pi^-,nt)$. These measurements are of particular interest in view of the mechanism of π absorption on a α cluster and the existing theoretical calculations$^{13)}$.

6) Information about single-nucleon emission (π^-,n), (π^-,p) would be obtained by studying the high-energy end of the non-coincident particle spectra.

EXPERIMENTAL SET-UP

For a complete kinematical determination of a two-particle-emitting process i.e. for the measurement of $|K_1|$, $|K_2|$ and θ we put down the following specificiations:

1) determination of $|K_1|$ and $|K_2|$ with 1% resolution.
2) determination of θ within 2%.
3) solid angle subtended by the counters 10^{-2} sr.
4) efficiency of the neutron counter about 10%.
5) reliable particle identification.

For practical reasons we shall perform the experiment in two parts. In the first set-up (Fig. 1) only neutron pairs will be detected. We intend to use the 70-MeV π^- beam of the CERN SC. The π^- beam, incident on the D_2O target, will be monitored in conventional way by the counter telescope: C1, C2, C3, C4. A start signal for the TOF system is obtained from C3. In order to discriminate against neutrons which are produced in C3, a thin (5×10^{-2} g/cm^2) counter C5 will be placed in front of the target. When using a thick target an additional thin counter, C6,will be inserted in the target in order to define the depth of the interaction point within 1cm. The two neutron counters will have the total dimensions 120 x 72 x 8 cm^3 each. The required momentum resolution of the neutrons will be achieved with a TOF system of 0.6 ns resolution and a flight path of 6m between the target and each neutron counter. To obtain this timing resolution the counters will be divided into subunits of the dimensions 120 x 6 x 2 cm^3, consisting of Pilot M plastic scintillator. Light from their ends is brought to fast bialkali photomultipliers via adiabatic light pipes. 8 subunits have one multiplier on each side. The localization of a neutron within one subunit is achieved by a time difference measurement between the two ends. To distinguish among different subunits inexpensive photomultipliersare coupled to individual subunits.

All counters will be connected with a Nuclear Data 50/50 system which includes a PDP 8/L and a magnetic-tape unit. A D_2O target will be used for the measurements, thus providing a permanent calibration and test of the counters by the $D(\pi^-,nn)$ reaction. The efficiency of the neutron counters will be measured at the Karlsruhe Isochronous Cyclotron.

The coincidence rate for the set-up of Fig. 1 will be about 1 per 3×10^6 stopped pions.

For the study of (π^-,np), (π^-,nd) and (π^-,nt) reactions the set-up is shown in Fig. 2.

The neutrons will be detected by the two neutron counters described above, but placed on the same side with respect to the target. On the opposite side a range telescope will be used. It consists of 40 plastic scintillators (40 cm x 40 cm area), viewed by 40 inexpensive XP 1110 photomultipliers. The varying thickness of the scintillators is chosen in such a manner as to keep a constant $\simeq$ 2 MeV energy resolution in the range from 20 to 100 MeV protons. The first of these scintillators gives also the TOF of the particles. A system of 5 wire proportional counters[10)] in front of the range telescope yields $\Delta E/\Delta x$ information. The charged particles will be identified by a combined information about range, a TOF and a $\Delta E/\Delta x$. A vacuum pipe (not shown in the figure) will be inserted between the target and this device in order to reduce energy losses in air.

To determine the ratio $W(\pi^-,nn)/W(\pi^-,np)$ within a definite energy range the range telescope will be used to detect neutrons as well. The neutron energy will be measured by a TOF system. For this purpose all plastic scintillators are viewed by fast photomultipliers.

Fig.s 1 and 2 show the arrangements for θ around 180°. By moving one counter we can measure the full angular distribution.

The experiment is intended to be done after the SC improvement. The approximate required number of shifts will be 100.

We ask for about 20 parasitic shifts at the 70-MeV channel, before the SC shut-down, for preliminary testing of various components. This is essential for the design of the final system.

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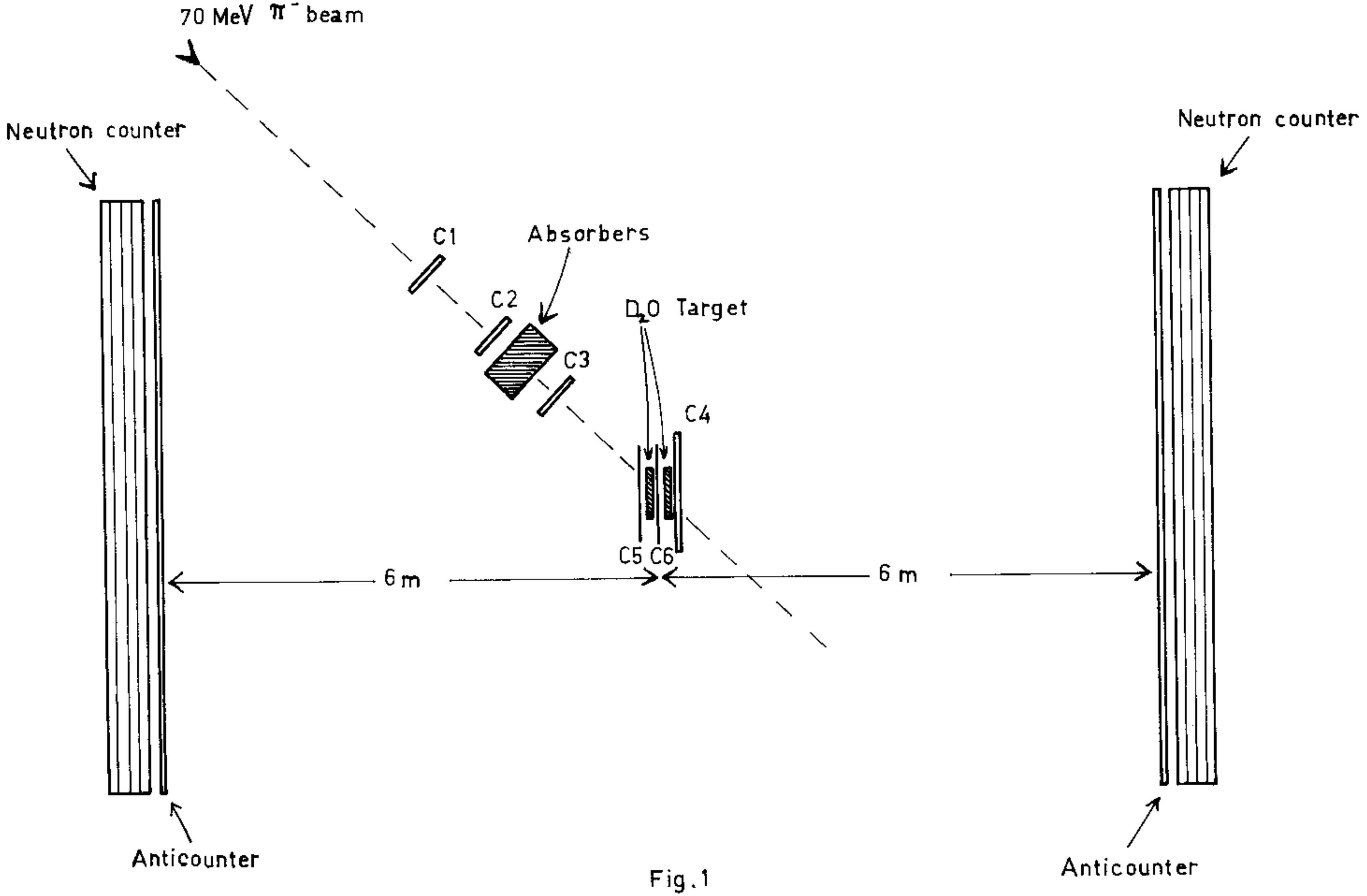
70 MeV π^- beam
Neutron counter
Neutron counter
C1
Absorbers
C2
C3
D_2O Target
C4
C5 C6
6 m
6 m
Anticounter
Anticounter

Fig.1

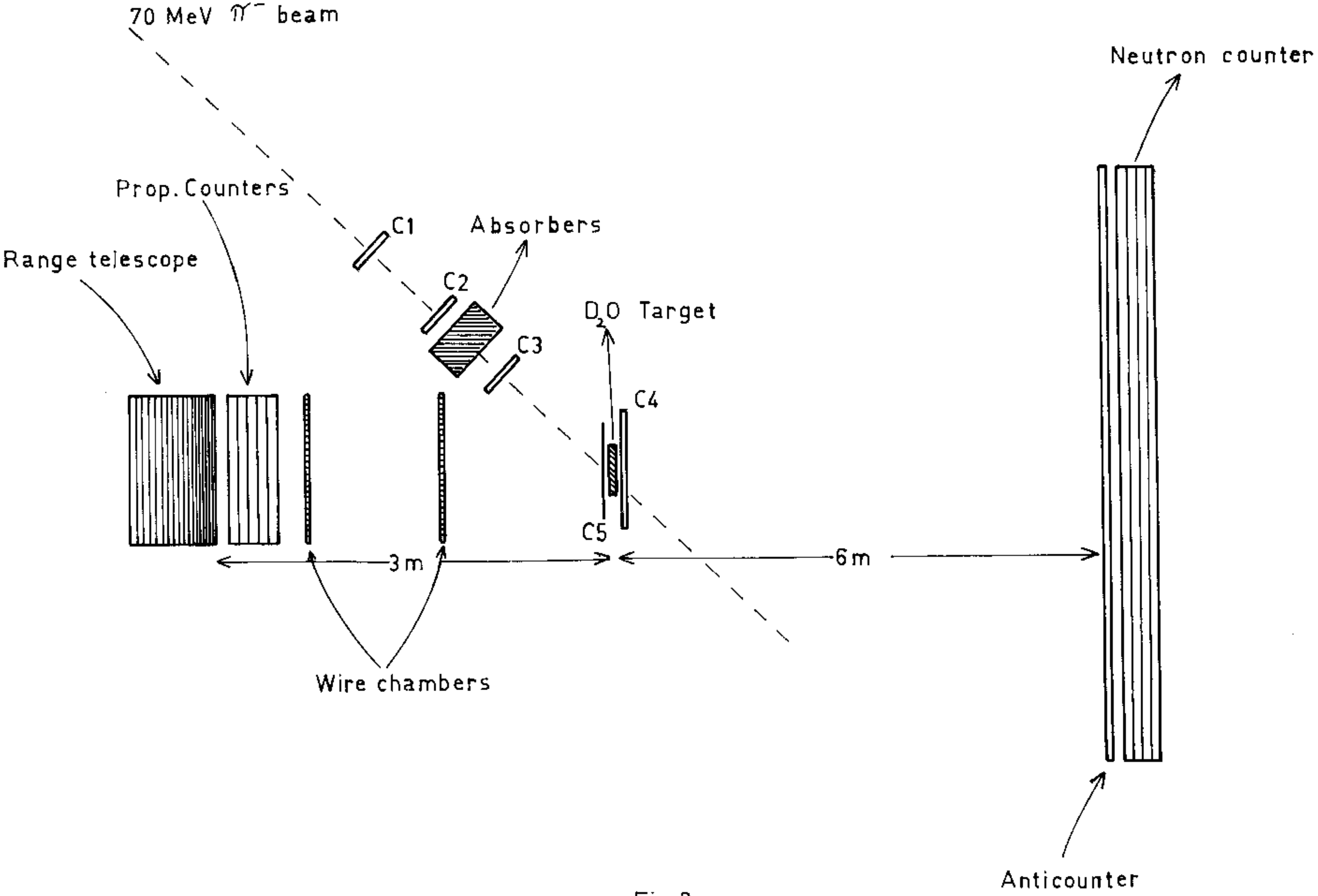
70 MeV π^- beam
Neutron counter
Prop. Counters
Range telescope
C1
Absorbers
C2
D_2O Target
C3
C4
C5
3 m
6 m
Wire chambers
Anticounter

Fig. 2