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

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In spite of the long delay since the initial submission of our proposal, the subject of pion absorption in complex nuclei is still of substantial interest. During this time due to the lack of high intensity pion beams experimental progress in this area has been limited. In the case of two nucleon emission the only new experimental result which should be mentioned concerns $^{12}\text{C}(\pi^-, np)$ as reported by Lee et al¹⁾, but only moderate energy resolution and statistical accuracy could be achieved. An interesting development during this period has been the increasing experimental evidence of absorption processes which involve more than two nucleons. This includes the observation²⁾ of strong (n,d) and (n,t) angular correlations from π^- absorption in ^{12}C . In addition, recent measurements of the de-excitation gamma rays following π^- absorption in a wide range of nuclei suggest absorption processes involving more than two nucleons³⁾. On the theoretical side there is little new work to report, either relating to the familiar two nucleon emission process, or to the newer more complex emission in which hardly a beginning has been made in understanding.

The above considerations suggest to us that many of the fundamental questions in pion absorption are still open, and that in spite of the delay of the SC improvement program our proposed experiment has retained its relevance. The experiment will have a substantially better energy resolution than has been achieved until now, capable of resolving final states in the residual nuclei, and the higher pion intensity will permit a correspondingly higher statistical accuracy.

The two attached figures show the slightly revised layouts of the two parts of the experiment. While the general design and goals of the experiment are unchanged, some details of the experimental apparatus have been altered. Thus, the two neutron counters which have been constructed each have the total dimensions $200 \times 48 \times 9 \text{ cm}^3$, consisting of subunits of the dimensions $200 \times 6 \times 1.5 \text{ cm}^3$, the scintillator material being NELL0. For the

charged particle range telescope the number of scintillator components will be reduced to nine, each of $80 \times 18 \text{ cm}^2$ area, and with the varying thicknesses chosen in such a manner that a combined TOF and range measurement will unambiguously identify the type of charged particle. The energy determination will be given by the TOF, with a time resolution better than 0.5 nsec.

One remaining change will be the use of one or more multi-wire proportional chambers to define the point of interaction of the stopping pion in the target. When using a thick target several chambers, of about $10 \times 14 \text{ cm}^2$ area, will be interleaved between layers of target material. With a thin target only one is required in front of the target. In either case the pion interaction point will be determined to within 1 cm.

In addition to the shifts which have been requested to carry out the experiment, we emphasize the prior need for parasitic beam to bring the neutron counters into an operational state. Since this stage can be done with beams of minimal quality and intensity, we would wish to have access to such beams long before pion beams of research quality become available.

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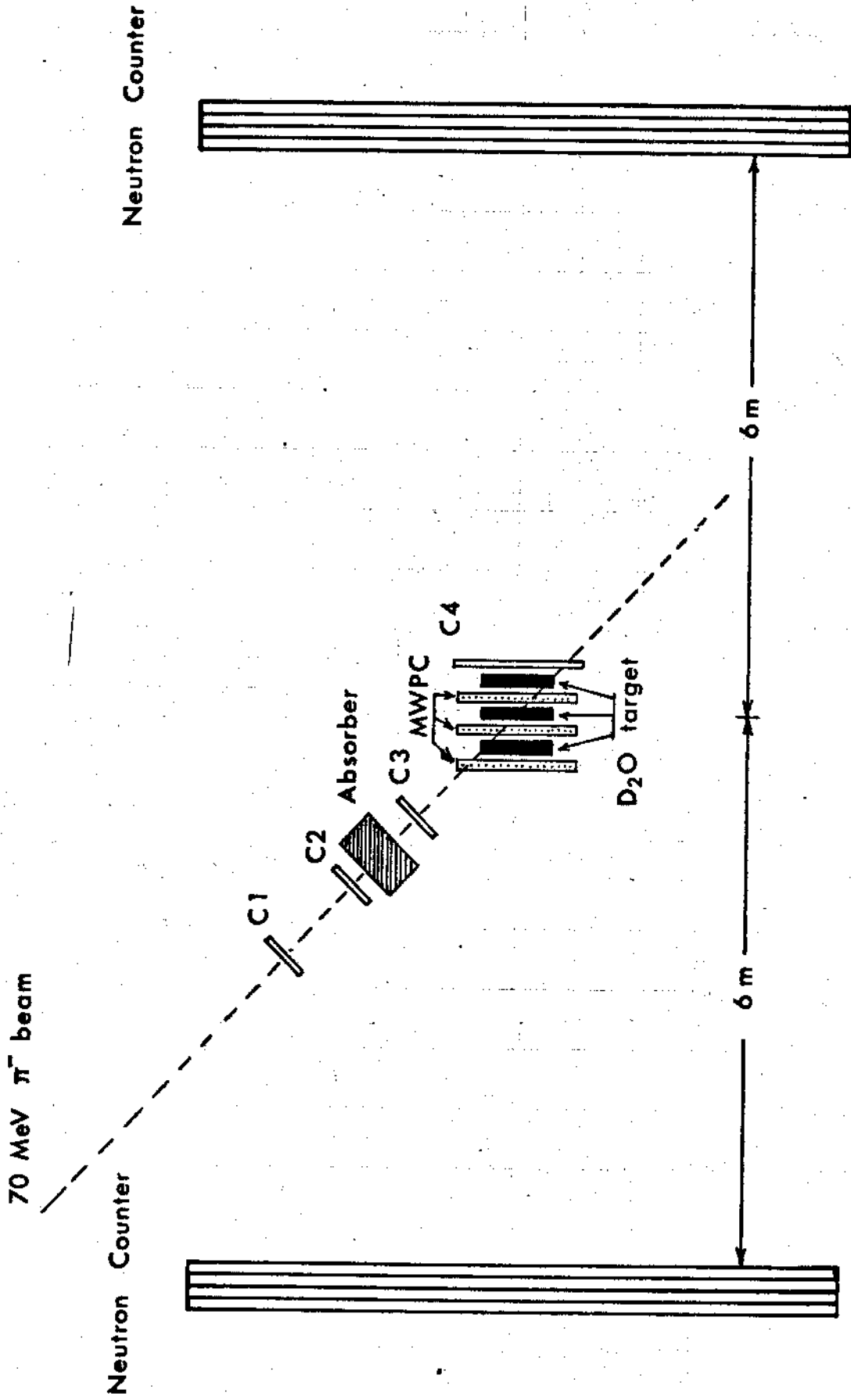


fig. 1

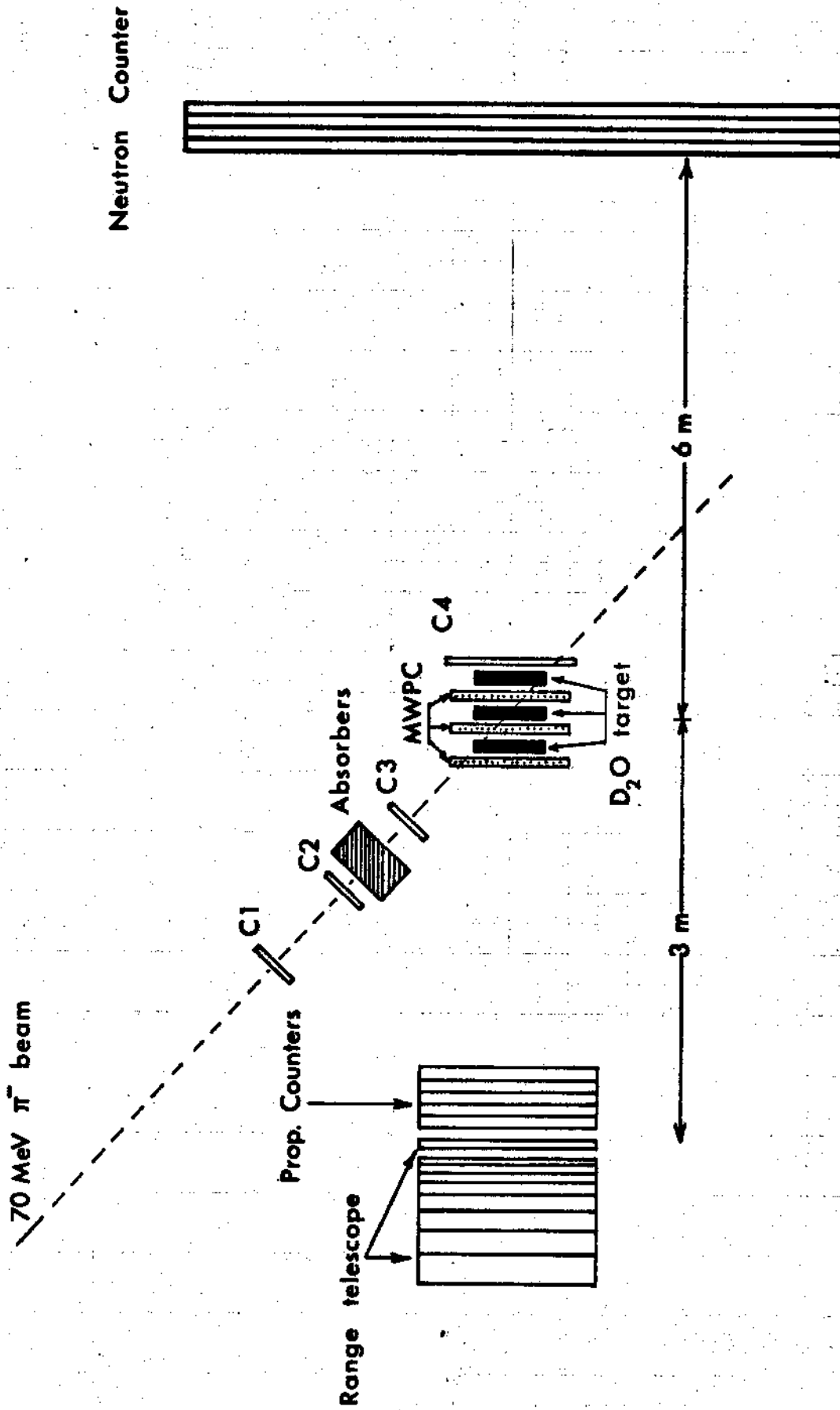


fig. 2

PHYSICS III COMMITTEE

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 π^+ 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 $(\pi, 2N)$ process, the more recent ones being the $(\pi^+, 2p)$ measurements of Favier et al.²⁾ on a large number of nuclei, the $^6\text{Li}(\pi^+, 2p)$ 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

*) 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 $^{12}\text{C}(\pi^+, 2p)$ cross-section as measured in a counter experiment²⁾ and in a bubble chamber⁸⁾, different excitation spectra in the same residual nuclei produced by $(\pi^-, 2n)$ ⁶⁾ and $(\pi^+, 2p)$ reactions²⁾, and different single-nucleon spectra⁹⁾ (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 pairs⁷⁾. The ratio $W(\pi^-, 2n) / W(\pi^-, np)$ is uncertain⁹⁾. Little is known about processes like (π^-, nd) and (π^-, 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 treatment¹²⁾ 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 approach¹⁾ 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 $\pi + 2N \rightleftharpoons N + N$ for which experimental information exists¹¹⁾.

Besides the absorption by a nucleon pair, the absorption by an α cluster¹³⁾ 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 invest-

igations. 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 calculations¹³⁾.

- 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 specifications:

- 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/cm²) 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 $120 \times 72 \times 8$ cm³ 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 $120 \times 6 \times 2$ cm³, consisting of Pilot M plastic scintillator. Light from their ends is brought to fast alkali 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 photomultipliers are 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 ≈ 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 counters¹⁰⁾ 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.

Figs 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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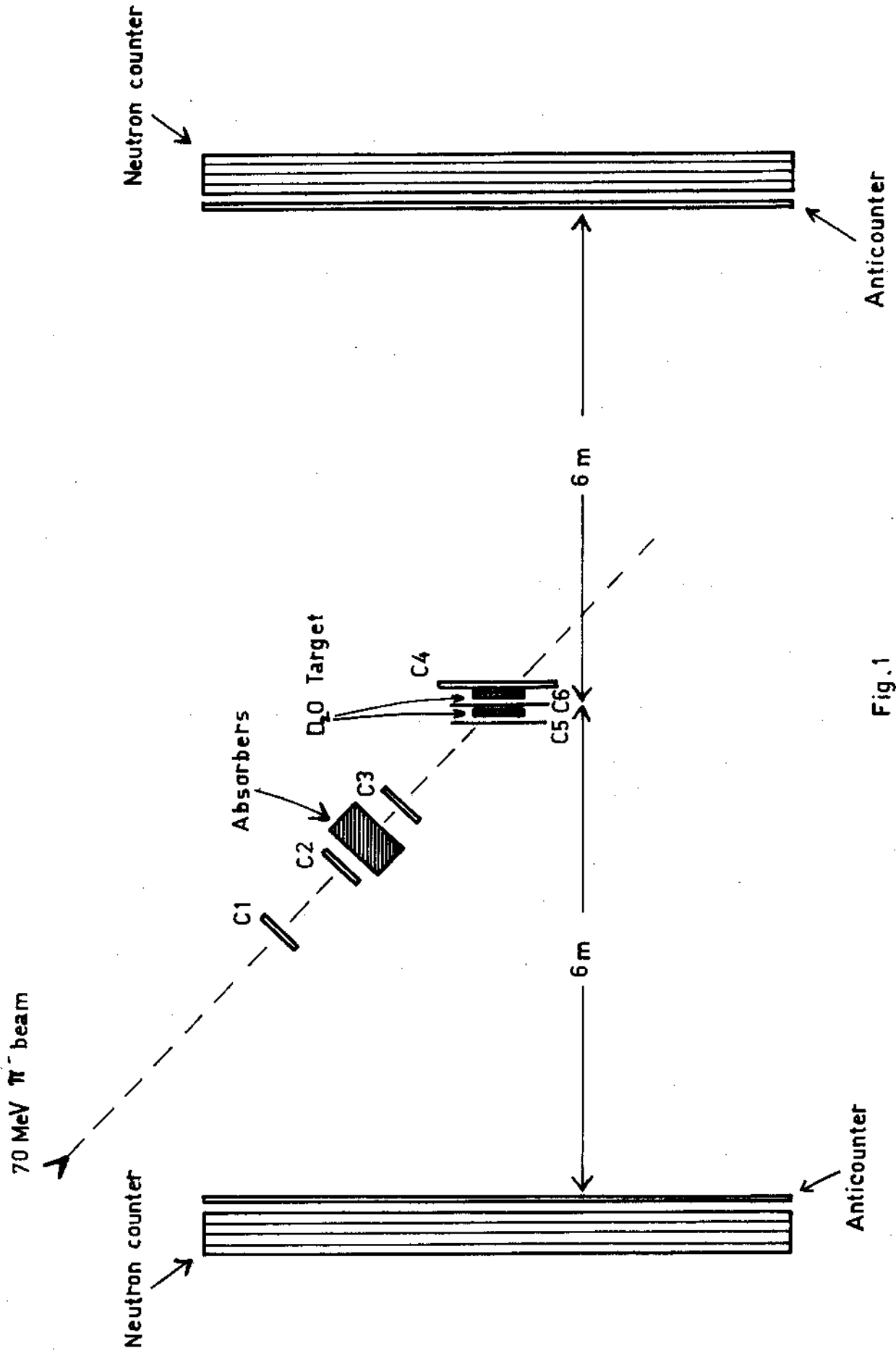


Fig.1

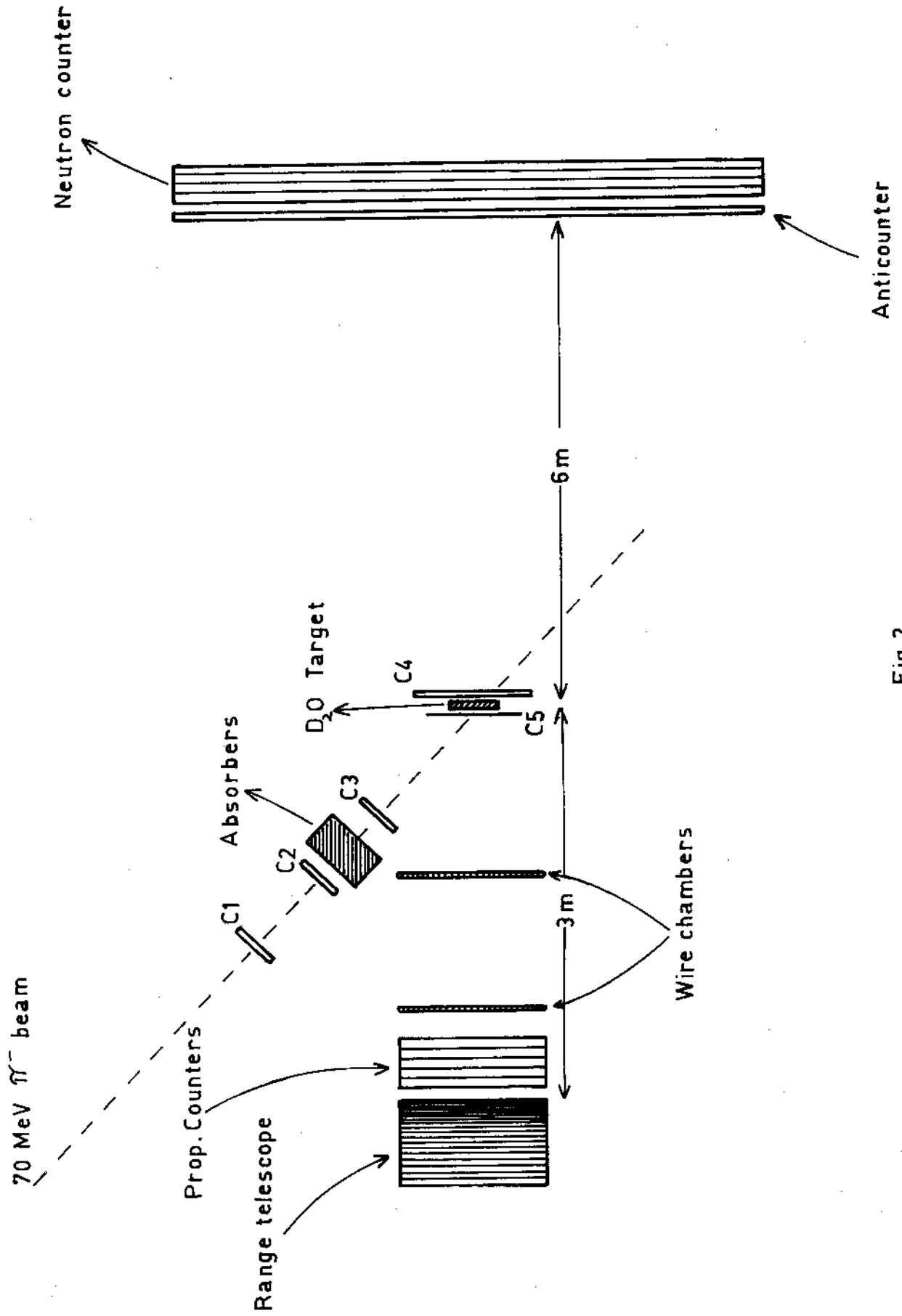


Fig.2