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A VISUALIZATION EXPERIMENT WITH CHARGED PARTICLES

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RESEARCH PROPOSAL

Los Alamos Meson Physics Facility

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SUMMARY

A visualization experiment with particular respect to radiotherapy with negative pions is proposed. The underlying basic concept is to trace charged particles with wire chambers. Two different methods are proposed: tracing the outgoing high-energy electrons ejected by high energy gamma rays after radiative capture of negative pions in coincidence or not in coincidence with the incoming pion (method 1) and tracing the outgoing positron from mu decay in delayed coincidence with the incoming positive pion (method 2). In method 1 a resolution of the order of 1 mm can be expected for a treatment volume at a depth of 10 cm under muscle when Compton effect in a low Z converter is used. Method 2 will yield a resolution of 7 mm. Both methods are three-dimensional. The experiment can almost entirely be done with existing equipment at the biomed channel. The rate of recorded events will be about 10^2/s. Five data-taking shifts plus two (maybe parasitic) check shifts are requested for a thorough test of the two proposed methods on a phantom. As much information on beam and scattering in water will be obtained, this work can very well be regarded as part of channel development.

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Information on the Experiment

Experimental area: biomed channel

Beam requirements

Particle type: positive pions, negative pions

Beam quality: low

Primary beam requirements: none

Running time required:

Installation: 24 h prior to beam time

Tuneup beam and setup: two shifts, maybe parasitically

Data collection time: five shifts

Scheduling: all major equipment existing and hence as soon as possible

Shielding and enclosures: no special requirements

Special services: none

Space required: as available at biomed channel

Hazards: no special hazards foreseen

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I. Purpose of the Proposed Experiment

The need for visualization of the interior of the human body under meson-particle irradiation has been emphasized by several authors[1-4] and shall not be reviewed here in detail. It shall only be recalled that visualization during the treatment is an important and unique feature of radiotherapy with pions. Methods for visualization experiments have been tried[3,4] or proposed.[1,2]

If one wants to visualize the treatment volume during irradiation with negative pions it seems to be most advantageous to observe the electrons ejected by high energy gamma rays from a thin converter, in coincidence with the incoming pion or not. This method will be called method 1. Figure 1 shows the setup; for a more detailed description see Sec. II.

If one wants an image with a dose as low as possible, it is essential to record as large a fraction of all events per incoming particle as possible. In this case every entering particle, preferably muon or positive pion, can be traced with two pairs of wire chambers. In the same way a large fraction of outgoing particles, i.e., electrons from mu decay, can be traced. This method will be called method 2. Figure 2 shows the setup; for a more detailed description see Sec. III. The obtained picture is truly three-dimensional.

II. Visualization Experiment Using Outgoing Electron Pairs from High-Energy Gamma Radiation

Negative pions stopped in tissue produce gamma radiation of about 100 MeV with a yield of about 2 percent. When passing through matter the quantum radiation can be converted into electron pairs or can knock out a Compton electron. In pair production the average angle θ_e between the direction of motion of a created electron (positive or negative) and the gamma ray is of

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the order $(mc^2/E)\ln(E/mc^2)$ where mc^2 is the rest energy of an electron and E is the total electron energy. For $E \approx 50$ MeV, one has $\theta_e \approx 5 \times 10^{-2} \approx 3^o$. Therefore one electron, or better the electron pair, can be used to determine the original gamma ray direction.

In Compton effect the distribution of the electron with respect to the high-energy gamma ray is again strongly forward-peaked. The average angle is of the order of mc^2/E and hence, for E = 100 MeV, one has $\theta_e \approx 5 \times 10^{-3} \approx 0.3^o$. Therefore the ejected Compton electron can well be used to determine the original gamma direction.

While traversing the converter (Fig. 1) the electrons undergo multiple scattering. If the traversed thickness is small enough the electrons are only slightly changed in their direction and still indicate the approximate direction the gamma rays came from. As the mean square angle $\sqrt{<\theta_s^2>}$ of multiple scattering varies about as the atomic number Z and the pair production cross section varies also about as Z, both quantities taken per g/cm^2, a normal plastic scintillator can very well be used as converter. Another suitable scintillating conversion material would be NaI(Tl).

When making use of the Compton effect, liquid hydrogen will be the most suitable converter material. As the setup with liquid hydrogen is difficult to build and to handle we do not propose to try it in this first experiment. One can simultaneously record the pulse height in the converter or, in the liquid hydrogen case, signals from a sandwich setup of converter foils and scintillation counters, and from that deduce the thickness the electron has traversed before escaping from the converter. In cases or in regions of the treatment volume, where good statistics are available, one uses then only electrons created close to the end of the converter, viewed in gamma

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ray direction, while otherwise one uses all recorded events. An anticoincidence counter is provided in the proposed setup to exclude recording of events caused by a charged particle entering converter and chambers.

Tables 1 and 2 summarize some data which are supposed to be typical. Note that Table 2 is thought to be of importance in a later experiment only. The resolution figures given in this paper should be understood as the mean deviation for one coordinate (square root of the variance of a Gaussian distribution).

Table 1

Typical Data for Method 1, Making Use of Pair Production

Electron energy	$\approx$ 50 MeV
Converter thickness d (in radiation lengths)	$\approx$ 0.02
Mean scattering angle $\sqrt{\langle\theta_s^2\rangle}$, averaged over d	$\approx 0.03 \approx 2^{\circ}$
Spatial resolution at 10 cm treatment volume depth	$\approx$ 0.6 cm
Solid angle	$\approx$ 1%
Total detection efficiency per gamma quantum (100 MeV)	$\approx 10^{-4}$
Total detection efficiency per pion	$\approx 2 \times 10^{-6}$
Rate of recorded events at 5×10^{7} pions/s	$\approx 10^{2}$/s

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Table 2

Typical Data for Method 1, Making Use of Compton Effect in Hydrogen

Electron energy	$\approx$ 100 MeV
Converter thickness (in radiation lengths)	$\approx$ 0.01
Mean scattering angle $\sqrt{<\theta_s^2>}$, averaged over d	$\approx 0.01 \approx 0.6^{\circ}$
Spatial resolution at 10 cm treatment volume depth	$\approx$ 1 mm
Solid angle	$\approx$ 2%
Conversion yield	$\approx$ 0.5%
Total detection efficiency per gamma quantum (100 MeV)	$\approx 10^{-4}$
Total detection efficiency per pion	$\approx 2 \times 10^{-6}$
Rate of recorded events at 5×10^{7} pions/s	$\approx 10^{2}$/s

Without recording incoming negative pions one obtains only the direction the gamma ray came from, and not the point where the pion came to rest. The combination of a larger number of these directional lines, preferably taken with two setups looking at directions perpendicular to each other (Fig. 1), will however, allow a good visualization of the treatment volume.

With recording of both the incoming negative pion and the outgoing high-energy gamma ray, one gets a truly three-dimensional picture. If necessary this experiment will be done at reduced pion intensity.

III. Visualization Experiment Using Incoming Mesic Particle and Outgoing Decay Electron

Although negative pions will be used for therapy a positive pion beam with the same stopping distribution in the volume to be treated can be simply obtained by reversing the polarities of all magnets in the pion channel. After coming to rest the positive pions decay producing an isotropic distribution of muons with energies of 4.1 MeV. These muons have a range of only

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1.5 mm in tissue and, with a mean life of 2.2 μs, decay into positron and two neutrinos. The positron spectrum extends to 53 MeV, with the maximum intensity at maximum energy. Multiwire proportional chambers, located above and to the side of the object being irradiated, are to be used to define the directions of incoming pion and mu-decay positron. A hardware delayed coincidence circuit will help in the determination of good events. Figure 2 shows the setup schematically. Table 3 summarizes data for a treatment volume 10 cm below the skin so that the incoming pions and the outgoing electrons traverse on the average 10 cm of human body which is assumed to consist of muscle.

Table 3

Typical Data for Method 2, Maximum Positron Energy Assumed

Incoming pion energy	≈ 52 MeV
Positron energy loss	≈ 20 MeV
π^+ resolution	≈ 7 mm
e^+ resolution	≈ 7 mm

IV. Machine Time Needs

The experiment shall be performed with existing equipment avoiding any major modification. A rate of 100 recorded events per second can be handled by the chambers and their data processing system. The necessary pion flux of about 5×10^7/s for both methods is easily provided. If one assumes a visualization volume of 1 ℓ and requires 1 recorded event per mm^3 a total data taking time of 10^4 s or somewhat less than 3 h is required per picture. Two shifts of data taking allowing at least four pictures (for example water depths of 20; 10; 5 and 0 cm in the water phantom) should be sufficient to determine the overall potential of one method and to check

the computations. For the two methods 4 shifts should be sufficient. An additional shift to try the Compton effect method would be highly appreciated, as well as two (maybe parasitical) check shifts. We ask, therefore, for a total of 5 shifts for data taking and 2 (maybe parasitic) check shifts. As much information on beam and pion scattering in water will be obtained the work can very well be considered as part of channel development.

V. Relation to Other Work at LAMPF

If the experiment can be performed successfully we think that at least one of the two methods will be continuously applied in connection with radiotherapy at LAMPF.

Method 2 of our proposal is not contained in any other LAMPF proposal. Method 1 of our proposal is partly and not in detail mentioned in proposal no. 83 of May 1971, among many other possible visualization techniques. In particular, no resolution estimates are given in proposal no. 83, and the scintillation converter technique described in our proposal is also not contained in proposal no. 83. Our method 1 in its final form, making use of the Compton effect, is not contained in any other LAMPF proposal, nor, to the best of our knowledge, anywhere else.

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FIGURE CAPTIONS

Fig. 1. Proposed setup for method 1, schematically. There is a hardware coincidence circuit for coincidences between chamber pairs 1 and 2 and scintillating converter, in anticoincidence with the veto counter. A similar setup of veto counter, scintillating converter and chamber pairs looks from below the drawing plane on the object (not shown in the figure).

Fig. 2. Proposed setup for method 2, schematically. There is a hardware coincidence circuit for delayed coincidences between wire chamber pairs 1 and 2 on the one hand and wire chamber pairs 3 and 4 on the other.

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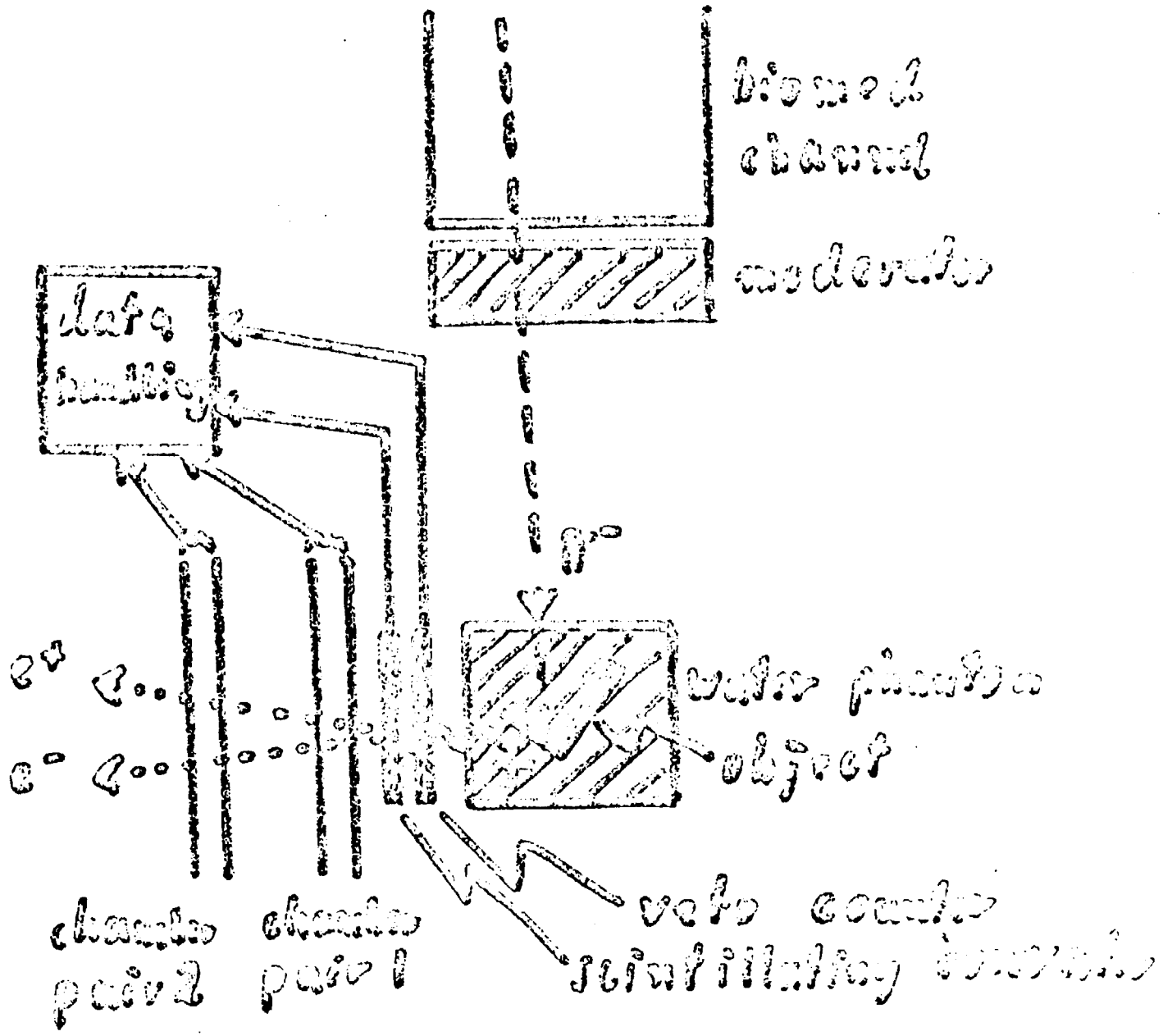

Fig. 1

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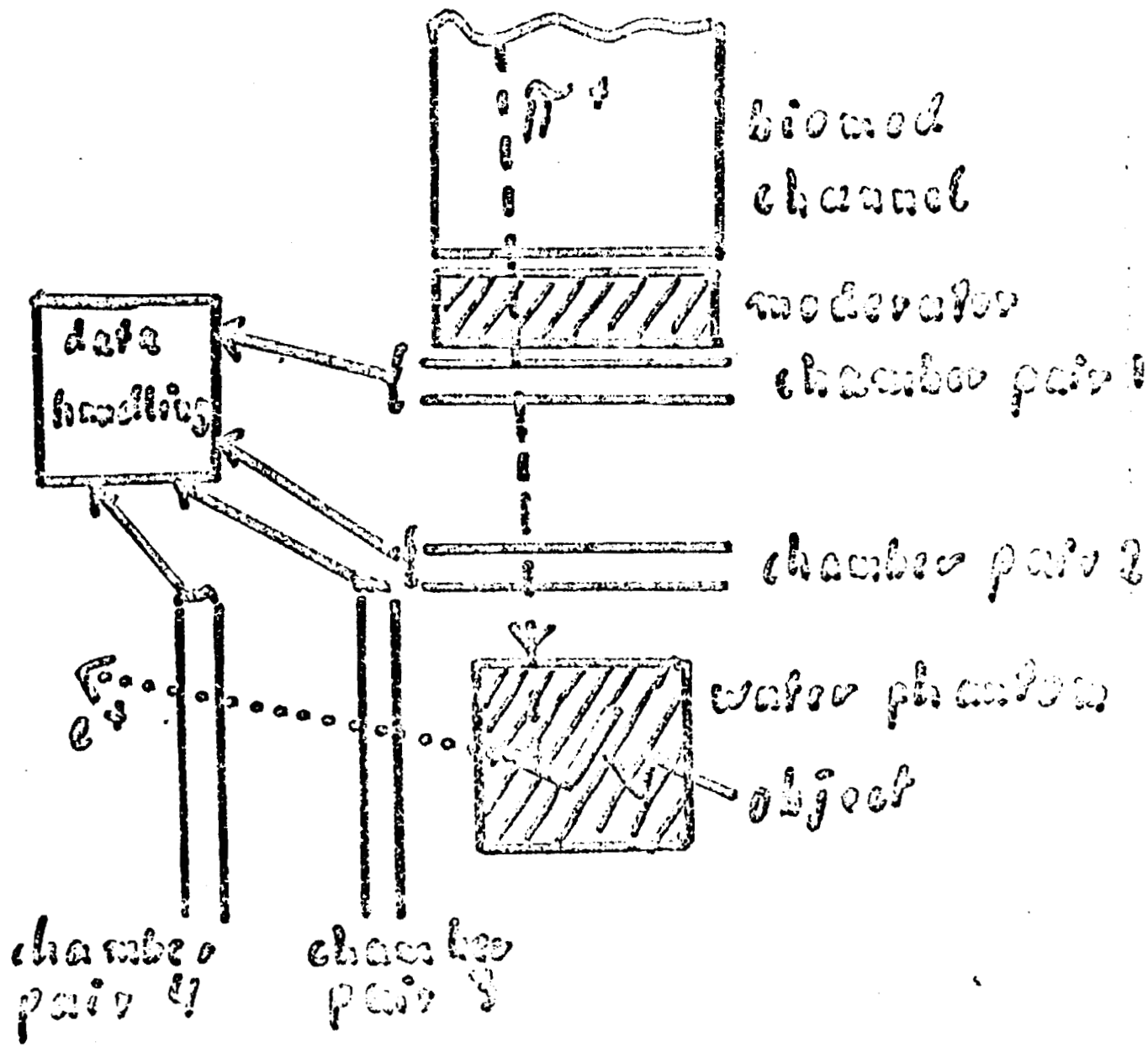

Fig. 2

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