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PROPOSAL FOR A STUDY OF (p,2p) REACTIONS AT 600 MeV

by

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I. INTRODUCTION

The intention to perform the experiment of this proposal was announced in a letter of intention of January 27, 1967, to the Physics III Committee (PH III-67/7).

Quasi-free-scattering experiments have recently been reviewed by Jacob and Maris(1) and Berggren and Tyrén(2). By quasi-free scattering we mean a process in which a high-energy particle knocks out a nucleon (or nucleon group) from a nucleus without further violent interaction taking place. The main observables are the separation energy, S, and the momentum $\vec{K}$ of the recoiling residual nucleus. Energy and momentum conservation yields:

$$T_o = T_1 + T_2 + T_{A-1} + S$$
$$\vec{k} = \vec{k}_1 + \vec{k}_2 + \vec{K},$$

where indices 0, 1 and 2 refer to the incident and the two fast outgoing particles. In order to determine S and $\vec{K}$ one has to measure both the energies and the scattering angles of particles 1 and 2.

Quasi-free scattering has been studied mainly in two types of reactions (p,2p) and (e,e'p). Experiments on the (p,2p) reactions have been performed for energies up to 1 GeV. Most of these measurements have been confined to the coplanar, symmetric situation, i.e. $T_1 = T_2$; $\theta_1 = \theta_2$; $\varphi_1 = \pi - \varphi_2$. In a few cases unsymmetric collisions with $T \neq T_2$ or $\theta_1 \neq \theta_2$ have been allowed. The (p,2p) experiments have revealed peaks in the separation-energy spectra corresponding to the knock-out of protons from various nuclear shells and subshells. It has been possible to identify the peak corresponding to the 1s shell in ^{16}O and lighter nuclei. The p shell may have been observed up to ^{32}S [3]. The momentum distributions for the recoiling nucleus have been analysed in terms of the distorted-wave impulse approximation. A qualitative correspondence has been established between the momentum distribution of the recoiling nucleus and the expected momentum distribution of the ejected proton.

So far experiments on (e,e'p) reactions have yielded information almost exclusively on the separation energies of knocked-out protons. For ^{75}As a 1s-proton separation energy of about 110 MeV has been observed[4].

2. PRESENT SITUATION REGARDING (p,2p) AND (e,e'p) EXPERIMENTS

The situation regarding (p,2p) experiments for incident proton energies higher than 300 MeV is the following. At about 400 MeV a study is in progress in Liverpool, but no results have appeared as yet. There seem to be problems connected with the determination of the proton energies resulting in worse energy resolutions than expected.

At about 600 MeV an experiment is being planned at the Virginia Associated Research Center[5]. The intention is to measure the energies and angles of the two outgoing protons in coplanar, symmetric (p,2p) reactions. According to Professor Perdrisat the experiment might be started during late 1968. It is to be noted that there is a fundamental difference between this experiment and the one proposed by us in that we do not restrict ourselves to symmetric reactions.

In Brookhaven, (p,2p) reactions were studied for two or three nuclei at an incident energy of about 1 GeV. The experiment was concluded at the end of 1966. No results have yet appeared.

At the electron synchrotron of Frascati (e,e'p) experiments have already been performed for some nuclei. The results give the first indications of very highly excited hole states with large intrinsic widths. To our knowledge the original set-up is dismantled and a new project is under construction(6). In the new situation one hopes to be able to measure also angular correlations and to study simultaneously (e,e'p), (e,e'd) etc.

3. PURPOSE OF THE EXPERIMENT

The main objective of the proposed experiment is the elucidation of nuclear structure as revealed in a study of (p,2p) reactions. It is to be noted that our experimental equipment is equally well suited for studies of (p,pd), (p,pα),(p,pπ) and similar reactions. We want to study coplanar or almost coplanar quasi-free scattering in symmetric as well as non-symmetric events, the symmetry in this case referring to energies and angles of the outgoing particles.

It is to be expected that at 600 MeV it will be possible to study hole states of high excitation corresponding to the ejection of a proton from an inner shell. The only experiment where, for instance, 1s protons have been seen above ^{16}O is in the study of (e,e'p) reactions. These latter studies suffer from several difficulties, mainly the very small cross section and the necessity to correct for radiative processes.

In previous (p,2p) experiments, on the other hand, multiple-scattering effects have prevented the identification of peaks due to proton knock-out from inner shells. It is therefore very important to look for quasi-free scattering from inner shells at higher energies where multiple-scattering background and other distortion effects are expected to be smaller. By including events which are asymmetric in angle as well as energy of the two emerging protons, the results can be used to test the distorted-wave calculations in larger details. Thus the momentum correlations inferred from angular distributions should be more reliable. Another advantage of the proposed set-up is the very much increased rate of data accumulation.

4. INSTRUMENTATION

The experiment is planned to take place in the proton room or in the new experimental area in the ISOLDE beam. The bigger space in the proton room would be appreciated, if the radiation level there can be tolerated. A lay-out of the experimental arrangements in the experimental area is shown in Fig. 1. The magnet size is a compromise between available space and momentum resolution. Two types of standard magnets (1 m type H, 1 m type C) could be used, of which we have shown type H in the lay-out.

The main advantage with the H magnet is the wider field and consequently larger angular acceptance. However, it has to be placed further away from the target which implies that one spark chamber must be placed in the rather large particle flux ($\sim 10^4$ p/s) in front of the magnet. If C magnets are used all spark chambers can come behind the magnets. Keeping the alternative possibility of using C magnets in mind we describe in the following the design shown in Fig. 1.

The particle trajectories are defined in momentum and angle by the thin target and the two spark chambers. With 2-mm-wide target and 1 mm spatial resolution of the spark chambers we get a momentum resolution of $\sim 3\ ^{0}/_{00}$.

A fourfold coincidence between the scintillation detectors is used to trigger the spark chambers. Pulse heights from the scintillation detectors are to be recorded and used to ensure that a (p,2p) reaction has occurred.

The desired angular range, 25° - 55°, cannot be completely covered without moving either the magnets or the target. Since, of course, it is much simpler to move the target along the beam direction we shall use this method.

The beam intensity will be monitored by means of a secondary-emission chamber and a two-scintillator telescope viewing the target.

He-bags will be used wherever possible in order to reduce multiple-Coulomb-scattering effects.

The accidental triggers due to the radiation background in the experimental area is expected to be low with the small beam intensity to be used.

5. DETECTORS AND ELECTRONICS

Spark chambers with magnetostrictive read-out will be used. We plan to use magnetic tape for data recording.

A block-diagram of the electronics is shown in Fig. 2.

The counting rate will be limited by the recovery time of the spark chambers. At a rate of 10 events/sec., estimates of the flux in the detectors indicate that the fraction of multiple sparks should be small.

6. REQUIREMENTS ON THE BEAM

We list the beam requirements for the proposed experiment.

$10^7 < I < 10^9$ protons/sec ;

ΔE of the order of 3 MeV;

beam size: present data acceptable;

time structure: best possible.

According to the information available at present the beam intensity is 2×10^{11} p/s and the beam size 20×30 mm^2. Due to our small target the useful intensity will be ~1/5 of the full value.

A further reduction is expected due to the need of a momentum slit between the two bending magnets in the ISOLDE beam line. The intensity reduction here is dependent on the present momentum resolution which is believed to be of the order of 2%. It seems reasonable to assume that the required beam can be obtained.

7. UPPSALA-CAEN-CERN COLLABORATION

A collaboration has been established between the Gustaf Werner Institute in Uppsala, the "Laboratoire de Physique Nucléaire" in Caen and CERN. In addition to the physicists who have signed the proposal P.U. Renberg, Uppsala and F. Bonthono, T. Lemeiller and J. Yonnet, Caen are prepared to take part in the experiment.

Financial support for a major part of the experimental equipment is secured through the Uppsala-Caen-CERN Collaboration, e.g. the scintillation detectors with necessary auxiliary apparatus will be supplied by the Uppsala group and the spark chambers together with scalers and most of the logic will be supplied by the Caen group.

Regarding bending magnets needed we have to rely on the possibility that they can be provided by CERN. The magnetic tape unit will be rented at the expense of Uppsala and Caen. It is hoped that part of the data-registration equipment can be borrowed from CERN.

The data analysis will most likely be carried out with the CDC-3600 at Uppsala in collaboration with the CAEN group.

8. TIME SCHEDULE

In order to study the possibilities of improving the energy resolution of the ISOLDE beam some machine time is needed preferably during the period September 1 to November 30, 1967. The tests would be carried out by members of the Caen-CERN-Uppsala collaboration together with the MSC Division.

During the second half of 1968 we should like to have 50 shifts divided into three periods. During this time it would be possible to study (p,2p) reactions in about 5 nuclei with good statistical accuracy. In the calculations we have assumed the following parameters:

- beam intensity : 10^{8} p/sec.
- target thickness : 0.2 g/cm^{2}
- solid angle : 2×10^{2} sr
- average cross section : 50 μb/sr^{2} MeV
- energy range : 100 MeV

With these parameters we obtain an event rate of 80 per sec. Clearly the cross-section is not a limiting factor.

9. REFERENCES

1 G. Jacob and Th.A.J. Maris, Rev. Mod. Phys. 38 (1966) 121;

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3 H. Tyrén, S. Kullander, O. Sundberg, R. Ramachandran, P. Isakson and T. Berggren, Nucl. Phys. 79 (1966) 321;

4 U. Amaldi Jr. et al., Att. Accad. Nazl. Lincei, Rend., Classe Sci, Fis, Mat. Nat., 41 (1966) 494;

5 C.F. Perdrisat and L.W. Swenson (private communication);

6 G. Cortellessa et al. (private communication).

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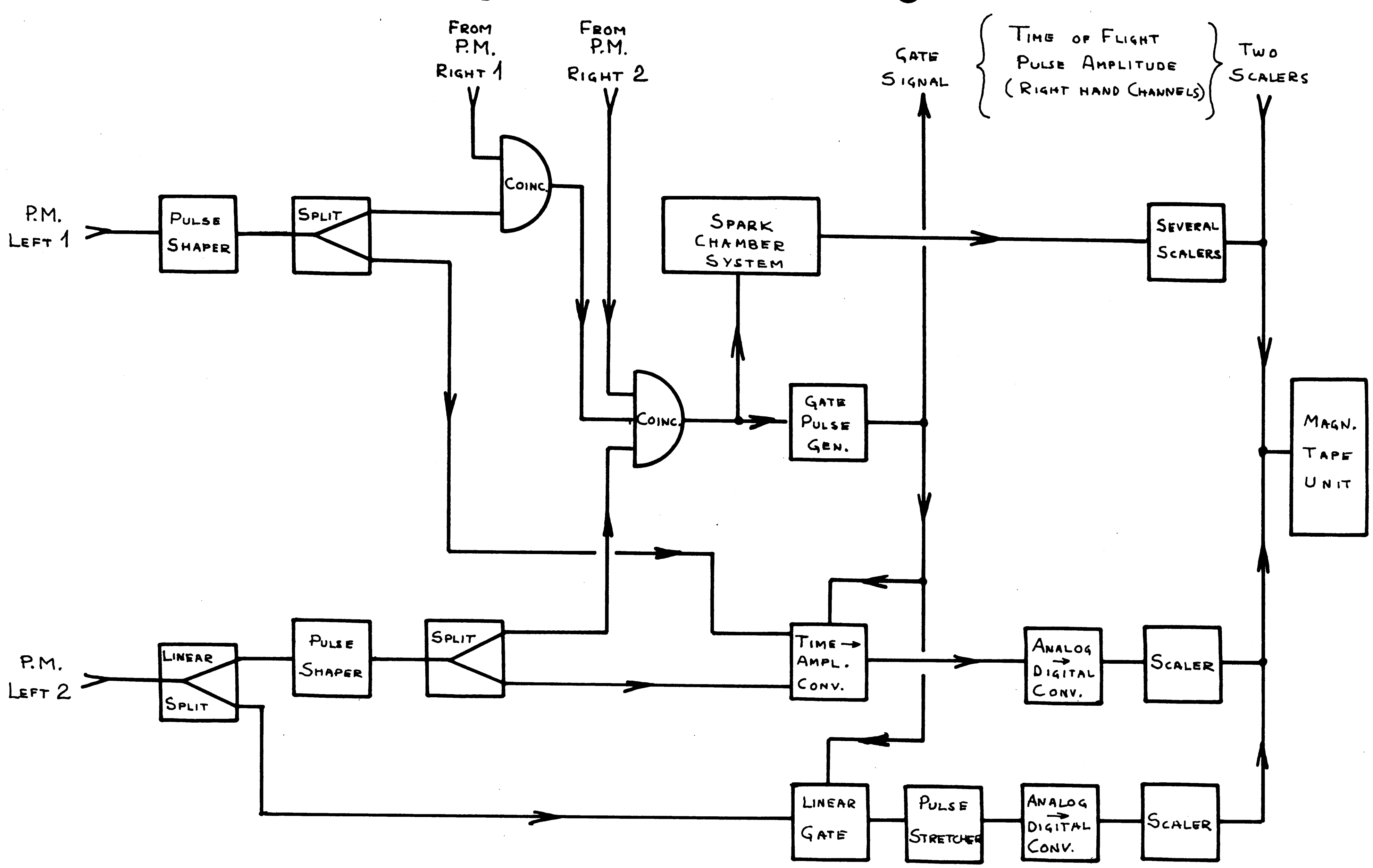

Adjustable Delay Units are not indicated

Fig. 1 Block Diagram of Electronics

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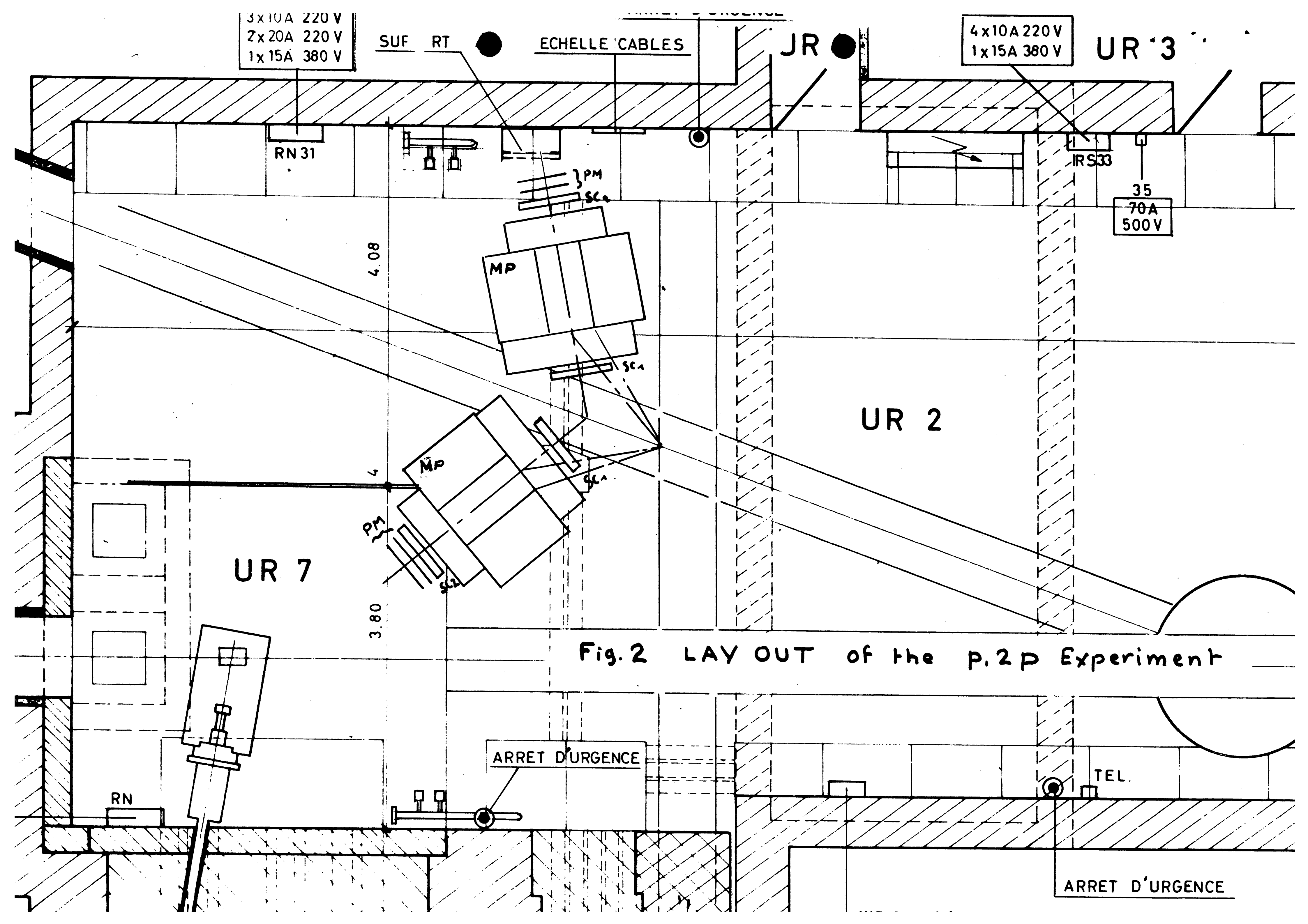

Fig. 2 LAY OUT of the p.2p Experiment