EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

PH III-74/57
5 December 1974

PHYSICS III COMMITTEE

A PROPOSAL FOR A LARGE ACCEPTANCE MAGNETIC SPECTROMETER FOR USE AT THE SYNCHRO-CYCLOTRON

by the

Omicron Working Party

Turin-Oxford-Grenoble-CERN-Birmingham-Amsterdam Collaboration

Spokesmen : T. Bressani, N. Tanner, B.W. Allardyce

GENEVA
1974

1. INTRODUCTION

The desirability of a large acceptance spectrometer, roughly a cubic metre or so of fairly uniform magnetic field with wire chambers and counters, arises from interest in certain rare events and weak effects which can be rendered visible only by the combination of large solid angle and momentum bite with good momentum and angle resolution. In effect, the proposed spectrometer is a common solution to several independent problems. The determination of the form factor from $\pi^- p \rightarrow e^+ e^- n$ by the observation of wide-angle pairs (large invariant mass) has the same practical requirements as the observation of the rare decay $\pi^0 \rightarrow e^+ e^-$; indeed, the former is the principal background for the latter. Apart from $e^+ e^-$ pairs, there are several other proposed experiments for which the physics has little relation, but the technique is quite similar; e.g. a measurement of the π^0 lifetime by $\pi^- p \rightarrow \pi^0 n$, $\pi^0 p \rightarrow \pi^+ n$, that is successive charge exchange scattering and detection of the π^+, requires just the same apparatus as pion double charge exchange on a nucleus. Similarly, low energy muon scattering and low energy pion scattering require very similar experimental arrangements. The practicality of several experiments with a large magnet at the SC is discussed elsewhere in this proposal.

Several features of the SC militate in favour of a large acceptance spectrometer:

a) It is expected that all of the best secondary beams will be made from the external proton beam for high extraction efficiency, and it is possible to deliver these secondary beams to one position in the Proton Hall, i.e. a fixed emplacement for a heavy magnet is acceptable.

b) A duty cycle as high as 80% is expected for the SC extracted beam and, as almost all interesting experiments have low rates and high backgrounds, duty cycle will often be a decisive factor.

c) The SC beam can be stacked and delivered with a time structure appropriate to muon decay experiments, a facility which is not available from cw machines.

The combination of the peculiarities of the SC and the large acceptance of the spectrometer proposed will offer a unique opportunity to do certain difficult but basic measurements, even when beam intensities elsewhere become superior to the SC. LAMPF have chosen to construct very high resolution spectrometers (EPICS, HRS), and SIN a more moderate, but still good, resolution spectrometer of higher acceptance. Neither has known plans for a large-acceptance low-resolution (circa 1%) spectrometer of the type proposed here, apart from a pair spectrometer for external γ-conversion which is a much more limited device.

The direct cost of this project, excluding work done at home institutions, is estimated at Sw.Fr. 876,000. The spectrometer could be ready for experimental work by the summer of 1976.

2. TECHNOLOGY

2.1 Magnet and power supply

The economics of this spectrometer project is heavily dependent on obtaining the use of an old bubble chamber magnet at Rutherford Laboratory known as the M11, and of a power supply at CERN.

A power supply designed for 2000 A at 500 V has been offered by the MSC Division and it is thought that it may be possible to take up to 2200 A at a lower voltage. The power consumption in the existing coils of the M11 would be a maximum of 250 kW or possibly 300 kW (for 2200 A).

The M11 magnet is illustrated in Fig. 1 in a form slightly modified from that in which it now exists. Over-all the magnet is roughly a cube of side 3 m, weight 185 t, with poles 186 cm long by 97 cm wide. As illustrated in Fig. 1 with 12 coils and a 22 cm spacer in the side of the yoke the gap between the sets of coils is 85 cm. It is estimated that a current of 2100 ± 100 A will give a field of about 10 kG at the mid-point, if the gap between the poles is also 85 cm. This field should be sufficient for the experiments contemplated at the SC. (A particle of 300 MeV/c bends on a 1 m radius in a field of 10 kG.) The field of 10 kG is limited by the power supply available, not by the coils which could take up to 8000 A giving a central field of about 20 kG.

The existing pole pieces of the M11 magnet were designed for a bubble chamber and are not at all suitable for a spectrometer. New pole pieces are required and it is expected that, with modest shimming, a field distribution can be obtained that deviates from the central value by less than 10% over a volume at least 80 cm wide × 75 cm high × 150 cm long. It is hoped to design the magnet poles using the computer program GFUN at the Rutherford Laboratory. The cost involved depends on whether new steel is purchased, or whether 'Liverpool' steel could be re-used.

Two other mechanical modifications of the magnet are considered to be very desirable. At present the upper set of coils, weighing 12 t, is supported by jacks resting on the lower set of coils. It is proposed to replace the jacks by brackets fixed to the sides of the yoke and tie bars to the roof of the yoke, the tie bars running in the space (about 5 cm) between the coils and the side of the upper pole. In this way, a great deal of space adjacent to the field region is made available for scintillation counter light-guides and cabling. Access to this space can be improved by separating the two blocks that form the side of the yoke to make a slot about 60 cm wide as shown in Fig. 1. This gap also provides a means by which the unspent beam can leave the magnet without hitting the yoke, after passing through the target. As it is not proposed to put any holes through the pole pieces these slots (one on each side) will be the principal access for cryogenic targets, etc.

2.2 Magnet box

Good momentum resolution requires the measurement of track coordinates by wire and drift chambers to an accuracy of 1 mm or better. Evidently, the chambers must be fixed in known positions to a higher accuracy which for design purposes is taken as 0.1 mm. The solution proposed is a strutted framework of box section stainless steel with something like the form illustrated in Fig. 2. Within the magnet the framework will be clamped to rails fixed to the sides of the yoke (see Fig. 1) and located with pins, but the framework will be removable by rolling it onto a duplicate set of rails fixed to the floor. It should thus be possible to mount chambers, counters, etc., on the framework with free access for accurate measurement and to be confident that the positions relative to the framework will be retained inside the magnet. In effect, the framework will provide the base of the coordinate system with respect to which all measurements, including the survey of the magnetic field, must be made.

The "duplicate set of rails" is not quite trivial as the accuracy must be no worse than the 0.1 mm specified; it will occupy a floor area of about 2 m × 3 m, plus access from all sides. In addition, it might be convenient if some beam could be delivered to the chambers and counters for tests after they are mounted and cabled, but before they disappear into the magnet.

The framework of Fig. 2 must be enclosed with panels to form a container for helium gas which is essential to reduce multiple scattering. It is no longer proposed[1)] to use pressures less than one atmosphere for the helium or for the chamber gas, as the forces on the magnet box are too large; thus the panels can be quite light and simple. Some of the panels will be required for cables and light guides via hermetic seals.

2.3 The site for Omicron

The proposed position of Omicron in the Proton Hall opposite pipe 'B' is shown in Fig. 3. The figure also demonstrates how various beams might be laid out to feed Omicron, at the same time allowing the use of the remainder of the Proton Hall for other experiments. With the magnet in this position, beams of pions, muons, protons and neutrons are all available as projectiles, but since there may be some advantage in moving Omicron further towards the north wall of the Proton Hall, the position shown in Fig. 3 is not completely definitive. Furthermore, the space requirements are somewhat larger than indicated there, since there will need to be rails beside the magnet on which the magnet box can be placed when it is being fitted with counters, etc., and when the alignment is made prior to pushing the magnet box into the magnet; such a table will occupy roughly 2 m × 3 m somewhere behind or to one side of the magnet.

At the SC, the beam height is 1.25 m above floor level and, in order to put the magnet centre at this height, the magnet must be put into a pit. The cost of such a pit is determined by its diameter and by its position in the Proton Hall, since the amount of reinforcing necessary to carry a load of 200 t is less as the north wall of the Hall is approached. In the interest of economy it was decided that there was not a sufficiently strong reason to have both rotational and translational freedom for the magnet in its pit, and consequently it is proposed that the magnet should be placed in a pit of diameter 4.8 m, which will allow rotation about a vertical axis, but no translation.

The magnet will be assembled to produce a vertical magnetic field (see Fig. 1) and it will be mounted on a slewing ring (taper rollers) capable of rotation to any angle about a vertical axis. There will be a precision in the horizontal plane of better than 0.1 mm as the magnet rotates, consistent with the over-all positional accuracy in the magnet box itself. The desired beams may then be fed into Omicron by a suitable choice of the angle of the magnet, and the position of the beam transport elements on the floor of the Proton Hall.

At some future date a scheme will have to be worked out to enable the civil engineering work and the magnet construction to be carried out in the Proton Hall without interfering too much with the normal experimental use of the hall.

2.4 Beams

Details of the secondary beams expected at the SC have been given by Allardyce et al.[2] and Cox et al.[3], and estimates of likely beam intensities at an Omicron position in the Proton Hall have been made by Tanner[1]. Work is continuing on the calculation of beams for Omicron, both on their intensities and on their properties (beam size, $\Delta\rho/\rho$). However, it is already clear that with Omicron sited as proposed, beams of neutrons, protons, muons and pions could be used.

Protons are an often embarrassing part of any π^+ beam produced at the SC, indeed being often 5 to 10 times more intense for a given momentum. Thus for protons up to $\sim$ 100 MeV there should be abundant fluxes in the Proton Hall. Higher energy protons may also be produced, by scattering from targets placed inside the bending magnet in the SC Hall; however, this has not yet been fully investigated. (The full energy proton beam cannot be taken to the Proton Hall for radiation safety reasons).

A neutron beam will be available via pipe 'B', using a deuterium target and the D(p,n)2p reaction at 0°. The flux of neutrons is expected to be 3×10^7/sec for the full energy of 595 MeV (assuming a 5 μA extracted proton beam from the SC).

It seems, however, that by far the most interest for Omicron attaches to pion and muon beams, at least in the first stages of the project. Some representative pion fluxes are given in Table 1, where it will be seen that typically π^- fluxes are a factor of 4 or 5 lower than π^+ fluxes.

Table 1

Possible beams

Particle	Momentum (MeV/c)	Target in SC Hall	Flux at Omicron
p	400	10 cm C	$\sim 5 \times 10^8$
n	1200	10 cm liquid D_2	$\sim 10^7$
π^+	480	10 cm liquid D_2	5×10^6
	400	10 cm C	1.5×10^8
	300	10 cm C	1.5×10^8
	200	10 cm C	4×10^7
	150	10 cm C	2×10^6
		Plus degrader in Proton Hall	
π^-	400	10 cm Be	2×10^7
	300	10 cm Be	4×10^7
	200	10 cm Be	1.2×10^7
	150	10 cm Be	5×10^5
		Plus degrader in Proton Hall	
μ^+	400	10 cm C	4×10^7
	150	10 cm C	1.5×10^7
		Plus degrader in Proton Hall	
μ^-	400	10 cm Be	5×10^6
	150	10 cm Be	7×10^5
		Plus degrader in Proton Hall	

Notes: Numbers calculated assuming an extracted proton beam from SC of 5 μA.
Duty cycle for Proton Hall ∿ 80%.
Degrading done by Be degrader from 200 MeV/c.
Momentum spreads typically $\Delta p/p = 7\%$.

The momentum range available is from about 150 to 500 MeV/c, with most flux between 200 and 400 MeV/c. Typically a pion beam of 400 MeV/c contains about 25% muons of the same momentum, the fraction increasing towards lower momenta. Thus experiments could switch from π to μ by changing the trigger with, for example, a DISC Čerenkov counter in the beam.

There is also considerable interest in very low energy or stopping pions and muons. It is proposed to obtain the low-energy pion beam by transporting the pions at 200 MeV/c or 300 MeV/c from the production target into the Proton Hall, and there to do particle identification followed by degrading in a beryllium degrader. This will cause an enlargement of the beam by multiple scattering, and a loss of flux by nuclear interactions. However, the resulting beam is still acceptable for Omicron, especially if some prior cleaning is done with a bending magnet just before the main magnet.

Low-energy muons may also be obtained in the above way, but in this case there is no loss of intensity due to nuclear interactions. Until the result of calculation becomes known, it is not yet obvious whether the best low-energy muon beam would be obtained this way, or by transporting the pions at lower momenta allowing more time for decay. In any case, it is clear that a beam degraded from, say, 200 MeV/c by 10 cm of beryllium will increase in area by some 7 cm^2 and in divergence by some 22 msr; this is by no means disastrous. In the case of pions, there is about 80% less by nuclear interactions.

2.5 Wire chambers

In order fully to utilize the potential of Omicron with the intense beams of fairly low energy expected at the SC, the detection devices should

i) have good spatial resolution
ii) have minimum material in the beam, to minimize multiple scattering
iii) be able to stand intense beams, with good resolving times.

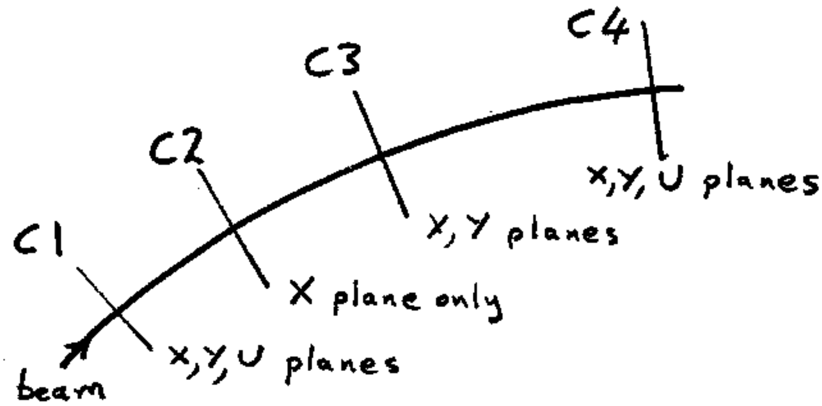
For a spectrometer of the Omicron type, the direction and momentum of the incoming particle is measured together with the directions and momenta of all outgoing charged particles, and the detectors must be arranged in the magnet such that this can be achieved (see, for example, Figs. 4 and 5).

Such considerations imply the use of multiwire proportional counters (MWPC) with spatial resolutions of typically 1-2 mm, or drift chambers with spatial resolution typically 100 μm whenever the fluxes are sufficiently low.

2.5.1 MWPC for the entrance channel

In order to determine the momentum of a particle in a homogeneous magnetic field, one must measure at least three horizontal (X) and two vertical (Y) coordinates at various points along the trajectory. (N.B. The X coordinates come from vertical wires, the Y from horizontal wires if the magnetic field is vertical). However, due to spurious pulses in the MWPCs, or when two particles arrive together, this minimum set of measurements gives rise to ambiguities. These can be eliminated by inserting more planes of wires, causing some redundancy of information. The arrangement suggested for the incident particles in Omicron is to use four chambers giving a total of 4X, 3Y and 2U (i.e. inclined) coordinates for each track; this then also allows reconstruction of the incident momentum even if one or more planes did not fire for any reason.

Unfortunately the inclusion of more chambers means that the multiple scattering is increased. The arrangement of planes is shown below, where the critical second and third chambers are kept to a minimum thickness.



The specification for the MWPCs is as follows:

Area: 10 cm × 10 cm

Sense wires: 10 μm gold-plated tungsten

Sense wire spacing: 1 mm

Sense wire plane/cathode plane gap: 4 mm

Cathode wires: 50 μm aluminium or beryllium copper, perpendicular to the sense wires

Cathode wire spacing: 1 mm

Windows: 10 μm mylar

Cathode plane/window gap: 2 mm

Gas filling: 1 atmosphere 'magic' gas, or argon/CO_2/ether.

The chambers specified here have their dimensions scaled from conventional 2 mm spacing chambers; the 1 mm spacing should not give problems on the rather small size of 10 cm × 10 cm required for Omicron. It is proposed to use 1 atm of gas in the chambers; in previous Omicron reports it was stated that $\frac{1}{3}$ or $\frac{1}{2}$ atm would be used. This, however, poses enormous structural problems for the magnet box design, as mentioned earlier, and this solution has therefore been abandoned. The MWPCs are instead made much thinner than is normal in order to counter the effect of increased multiple scattering at 1 atm pressure. Note that atmospheric pressure helium will be substituted for air in the space surrounding the chambers in the magnet box.

Development work is under way to determine the best gas mixture for our purposes, and to investigate whether aluminized mylar foils could act both as cathode planes and windows, thereby reducing the total amount of material present.

The momentum resolution obtainable from reconstructed tracks will depend on the multiple scattering and on the wire spacing in the chambers. A 1 mm spacing leads to a momentum resolution of about 0.2% for a deflection angle of 1 radian. The corresponding number for the momentum resolution caused by multiple scattering in the chambers C2 and C3 is 0.3% for 100 MeV/c particles, and 0.1% for 400 MeV/c. This is doubled whenever the particle hits one of the wires in the chambers.

2.5.2 Drift chambers

Drift chambers will be used to measure the trajectories of particles emitted from the target (except for the chamber closest to the target where the rate will be too high), because here the local counting rates will be low.

There has been impressive progress recently at CERN in the drift chamber field[4], and advances have been made, whilst retaining the 100 μm accuracy of the devices. However for Omicron, such a precision is unnecessary, but it does mean that the momentum resolution is here determined entirely by the multiple scattering. Since the total thickness of material traversed is smaller in a drift chamber than in a MWPC, the resolution on scattered particles will be rather better than that on the incident particles.

In general terms, the scattered particles will be detected in "rings" of chambers of which the closest to the target will be of the MWPC type. In practice, since it is much simpler to construct planar chambers, these "rings" become polygons. However, one possible future development is towards cylindrical drift chambers, and work on a prototype has in fact already started at CERN (an ISR group). If such chambers were successfully developed, then a genuine cylindrical arrangement would be possible causing large gains in the off-line reconstruction time of events on the computer.

Another exciting possibility is that of reading both X and Y coordinates from a single sense wire by means of the induced signal in a delay line placed behind the sense wire[5]. Delay times of the order of 2 to 4 nsec/cm have been obtained, which means about ±3 mm vertical accuracy if timing to 1 nsec is attempted. It is hoped that this technique can be developed and used in conjunction with the cylindrical chamber development mentioned above. Another possibility to obtain X and Y information from one wire is current division, and this also will be investigated.

A summary of the dimensions of the proposed chambers is given in Table 2 and Fig. 4 or Fig. 5.

Table 2

Summary of chambers

	Distance between sense wires (cm)	Type	Position	Size (cm^2)	Planes of coords.	No. of wires
C1	0.1	MWPC	Incident beam	10 × 10	X,Y,U	300
C2	0.1	"	"	"	X	100
C3	0.1	"	"	"	X,Y	200
C4	0.1	"	"	"	X,Y,U	300
C5	0.1	"	Scattered beam	20 × 20	X,Y,U	600
C6	2.5	Drift	"	40 × 70	X,Y	44
C7	5	"	"	50 × 100	X	20
C8	5	"	"	70 × 150	X,Y,U	75

2.6 Chamber electronics

Of the several systems in use or under construction at CERN, there seem to be two which are interesting for Omicron, bearing in mind that we have only a limited number of wires, that there may be high count rates, and that there is a strong magnetic field present. There are:

1) the system developed by Lindsay et al.,[6] with receiver and memory module type 4173;

2) the system developed by the TCL group.

Both systems have several common features:

i) the only circuit left directly on the chamber is the preamplifier;

ii) the non-standardized signals are sent via twisted pair cables to the electronic channel;

iii) the modules for the processing of the signals fit into CAMAC crates (16 wires/module for standard NP, 32 wires/module for TCL). The problem of interfaces is thus greatly simplified because a standard CAMAC-to-computer interface can be used.

The differences between the two systems are essentially the following (apart from the factor of 2 in compactness in favour of the TCL):

a) the NP standard system with type 4173 RM modules has no active delay. The delay is obtained by adjusting the length of the twisted pair cables. Thus, there is no electronic dead-time. Unfortunately FOR and MAJ outputs are not available.

b) the module of the TCL system consists of receiver, delay and memory for each wire. The delay is fixed at 600 nsec, obtained by using a chain of three monostables. The electronic dead-time is thus reduced to 200 nsec. FOR, MAJ and MOR outputs are provided. Two memories in series are used for each wire, as a special feature for fast-decision hardware analysis.

The price of the two systems is approximately the same, i.e. Sw. Fr. 80 per wire including cables, connectors, mechanics of the CAMAC crates, etc. Power supplies and interfaces of the CAMAC crates are excluded, and amount to $\sim$ Sw. Fr. 20 per wire. Thus a good estimate for the <u>complete</u> electronic chain from the wire into the computer is Sw. Fr. 100 per wire.

The TCL system seems more attractive, because it does not need modifications for use in Omicron, the only drawback is the dead-time of 200 nsec, which is indeed acceptable for the expected counting rates ($\sim 2 \times 10^5$ per wire per sec). The standard NP system would need some modification in the modules in order to provide FOR and MAJ outputs.

Concerning the electronics for DRC, we recall that in order to have a 100 μm spatial resolution, one needs a time resolution of 2 nsec. In the system developed by the NP Electronics Group this feature was achieved using a clock at 125 MHz with four parallel channels in delayed coincidence. For the use in Omicron, where accuracies of the order of 1 mm are requested, the use of a simple clock of 125 MHz is sufficient. The complete electronic processing chain from sense wires of the DRC to the CAMAC crate (preamplifiers on the wires, discriminators, time measuring device, etc.) are available from the CERN NP Electronics Group.

Several optional functions on the modules are provided, and the price of a complete electronic chain per wire is in the range Sw. Fr. 200-400, depending on the requested options. The price could be thus evaluated as $\sim$ Sw. Fr. 300 per wire, since Omicron will not require the more elaborate options.

2.7 Data acquisition

The CAMAC system mentioned above should feed a small on-line computer, such as the Nord 10 with 32K memory. This will enable the data to be collected onto tape, but simultaneously will allow presentation of a section of the data, together with an elementary analysis.

It may be necessary eventually to do some form of pre-processing of the data either by using the fast OR outputs mentioned above, followed by NIM coincidence units and gates, or by building special purpose pre-processors. Indeed, one advantage of a Nord 10 computer is that there is a fast direct memory access facility allowing just this sort of fast pre-processing.

Once the data is in the computer, it will be necessary to perform tests on the goodness of the event not done beforehand, to test the efficiencies of detectors, to analyse the spectra of scintillators, to carry out book-keeping functions, to write the raw data to tape, and to do some analysis (momentum reconstruction, etc.), which should be available for display when required. This last operation will presumably be carried out on a fraction of the data, not every event. Maximum event rates will be of the order of 100 per sec in order not to overload the system.

The computer configuration necessary to perform these tasks would consist of, for example, a Nord 10 computer with 32K memory, a CAMAC interface, direct memory access facility, a disk controller (4 disks), a magnetic tape transport unit, a card reader, a teletype, and a display unit; a fast plotter/printer would also be a distinct advantage. Although a Nord 10 has been mentioned as a desirable computer, other equivalent computers are certainly not excluded.

2.8 Off-line computing

It is intended to produce a program chain similar to that used at the SFM consisting of

i) Simulation (i.e. tracking in the magnet, including intersection with wire planes, multiple scattering, background generation from δ-rays and nuclear reactions, energy loss, etc.).

ii) Track finding (i.e. the association of signals into groups called 'tracks', which have to obey various constraint criteria).

iii) Geometry (i.e. confirmation that what has been called a track remains so under tighter constraint condition, a fit to the momentum of each track, a fit of tracks to a vertex, search for decays, etc.).

The output from such a chain consists of the vertex of the event, the momentum vectors for all particles observed, and an error matrix. A final stage, called 'kinematics' can then decide on the physics of the event.

The programs will be modular in form in order to allow the changes in experimental apparatus, which are bound to occur from time to time, and in order to allow different experiments to be computed with only minor modifications to the program.

The simulation of several experiments is already under way and preliminary results have been produced.

The production of a tape containing simulated data is a very important first step, since it allows development and testing of the track-finding programs to be carried out in parallel with the mechanical/electrical installation of the Omicron magnet (i.e. a start can be made immediately on the difficult task of track finding).

There is considerable experience of track-finding problems at Omega and SFM, but the problems encountered there should be very much reduced at Omicron. At Omega where the field is reasonably homogeneous and there are many detector planes, the parametrization technique works well and is very fast. At SFM, the field shape is very badly behaved and there is little redundancy of information along a track. Omicron is thus more like the SFM than the Omega spectrometer.

However Omicron differs fundamentally in that:

i) the field shape is reasonably good (probably constant to 10% over most of the volume),

ii) the multiplicity is lower (never more than about 3),

iii) the energy is much lower, hence less background, but more multiple scattering,

iv) there is no beam tube as at SFM, which there is responsible for the generation of a background higher than the real event rate.

These facts mean that the computing problem at Omicron will be very much simpler than at SFM; the main problem areas are

i) the low redundancy (because of multiple scattering it is desirable to have rather few planes),

ii) possible spiralling of low-energy particles,

iii) δ-rays firing many wires in one plane,

iv) cases where particles do not originate from the vertex (e.g. decays, secondary interactions).

However, following the advice of the CERN DD Division, it is intended that there be enough chambers in both primary and scattered beams to give 4X, 3Y and 2U coordinates along each track. The redundancy thus gained will enable the above problems to be overcome easily.

It is intended that the parametrization technique for track finding be used if at all possible, since one gains a good deal in speed in this way. Following the suggestion of the DD Division, we are investigating whether cylindrical chambers can realistically be used in Omicron for the scattered particles; this would increase the speed of the programs and make them simpler to write. However, for the present the program development is going ahead on the assumption of a parallel polygonal structure for the chambers in the scattered beam.

As far as the 'geometry' section of the program chain is concerned, not much work has been done so far. However, standard methods and programs exist and there should be no special problem in adapting them to Omicron.

Upper limits for computing time have been estimated by H. Grote (CERN DD) as:

track finding: $10 + 2n^3$ msec/event

geometry : $50n$ msec/event

where n = number of charged particles after scattering (1, 2 or 3 for Omicron). There are good reasons for believing that the time quoted for the geometry program may be reduced enormously (e.g. by a factor of 10) for Omicron. The above estimates are given as times for the CDC 7600.

3. EXPERIMENTS

Of the many experiments which require or would benefit from a magnet like Omicron, interest of the participating groups has focused on the following, which, it will be seen, fall into groups requiring very similar experimental arrangements.

3.1 Muon scattering (also pion scattering) at low energies

3.1.1 Muons

The use of muon beams to probe nuclear properties has not been fully exploited, and in particular, the scattering of low-energy muons on light nuclei has never been studied. Ericson has pointed out that low-energy ($\lesssim$ 50 MeV) muons, being non-relativistic, might allow measurements which could never be performed with (relativistic) electrons. In particular, the radiative connections for low-energy muons are very small, and due to the large rest mass of the muon there may be nuclear effects which are detectable.

It is proposed to study large-angle Mott scattering of low-energy muons on ^{4}He. Both μ^+ and μ^- beams will be used, and the experiment consists in observing a difference in this scattering between the μ^+ and μ^- due to the electric polarizability of the ^{4}He nucleus. The cross-sections are of order 1 μb/sr in the backward hemisphere and it is calculated that the effects to be observed are of the order of at least 1% in the cross-section (corresponding to changes of 5% in the r^2 term in the expression for the scattering amplitude).

The proposed experimental arrangement is shown in Fig. 5. We will use a muon beam degraded to $\sim$ 150 MeV/c by a beryllium absorber, as mentioned earlier. By focusing and analysing the beam after the degrader we should obtain fluxes at Omicron of at least 5×10^5 μ^- per sec and of the order of a factor 10 more for μ^+ (within a momentum bite of 7%). There will be strong pion contamination in these beams, but separation can be achieved by a good identification of the beam particle prior to the degrader (using a DISC Čerenkov), and by a range array at the exit of Omicron (see Fig. 5). In addition, a bending magnet following the degrader, and before the Omicron magnet, will eliminate the unwanted pions due to the approximately 10% momentum difference caused by the degrader. The trigger will be a coincidence $S_1S_2S_3S_4S_6\overline{A}\overline{S}_5$.

The resolution of such a configuration is about 1 MeV intrinsically, with a rather larger ($\sim$ 3 MeV) spread arising from the finite ^{4}He target thickness. However, in this particular case, the energy resolution is not critical. A study of the layout of the detectors is being made using the simulation program referred to earlier. This shows that with the set-up shown in Fig. 5, all the muons scattered at angles from 160° to 180° and about 15% of those at angles from 90° to 160° are accepted; this corresponds to a solid angle of about 1 sr. It is hoped to improve this geometric acceptance by changing somewhat the positioning of the detectors. With a target of 10 cm of ^{4}He (liquid) and a beam of 5×10^5 per sec, a count rate of about 10^4 events per day is achieved for each μb/sr of cross-section at the backward angles. They should be adequate to provide the necessary statistics.

3.1.2 Pions

It should be mentioned that the same apparatus, with minor changes, can be used to detect backward scattered pions, but the geometric arrangement would have to be altered to observe forward angles.

Elastic and inelastic π-nucleus scattering at large angles can yield very useful information to help check the proposed models for the π-nucleus interaction at energies below the 3-3 resonance. For instance, a detailed analysis carried out by Beiner and Huguenin[7)] has shown that the backward angle elastic scattering data are essential in order to solve the ambiguities in the choice of a consistent set of phase shifts.

Since for pions the cross-sections are very much larger than for muons, the necessary statistics should be able to be collected in a short time.

3.2 Detection of electron-positron pairs after π interactions or decay

There are several experiments for which one needs a similar detection system for the measurement of the energies of the electron-positron pair produced by a π decay or by a pion interaction. These are:

i) $\pi^0 \to e^+e^-$;

ii) $\pi^- + p \to n + (e^+e^-)$ with π^- at rest;

iii) $\pi^\pm + {}^A_Z X \to {}^A_{Z\pm1}X + \gamma$ (detection of γ by external conversion) with $\pi^\pm$ in flight.

$$\hookrightarrow {}^A_{Z+1}X + (e^+e^-)$$

The quoted experiments can give information on several different physical processes relevant to particle physics and nuclear physics. They are classed together because from the experimental point of view the requirements are similar, i.e.:

a) counting rates are expected to be quite low for all the reactions;

b) good energy resolution is needed in order to discriminate the desired events from background.

Thus one needs a large solid-angle of detection associated with a good energy resolution. Magnetic analysis is the best technique to achieve these goals.

In connection with the different experiments, beams, trigger and targets are different, but the configuration of the chambers inside the Omicron is the same.

3.2.1 Decay of π^0 to a single lepton pair

No experiment to measure the decay $\pi^0 \to e^+e^-$ has been reported, but estimates of the branching ratio compared to the two-photon decay mode have been made. The various calculations of the branching ratio assume different mathematical formulations for the pion form factor and it is seen from Table 3 that values from 5×10^{-8} to 22×10^{-8} are obtained. The unitarity limit is model independent and consequently a comparison with an experimental result is very important, since a value less than this limit would imply a phenomenon such as a CP violating current. If, however, the experimental result is in the range of a few times 5×10^{-8}, then it could be used as a test of the model for the pion form factor, or as a guide to the construction of future models.

Table 3

Calculated branching ratios for $\pi^0 \to e^{\pm}$

Model cut-off parameter	$B_{\pi^0}(\times 10^{-8})$	Reference
Unitarity	4.7	(b)
1.0 m_π	4.7	(a)
1.4 m_π	4.7	(b)
3.16 m_π	6.7	(b)
5.7 m_π	6.4	(c)
6.95 m_π	12.0	(a)
7.6 m_π	6.1	(c)
9.8 m_π	5.7	(b)
10.0 m_π	4.9	(c)
13.9 m_π	22.0	(d)
Baryon loop	14.0	(a)

a) S. Drell, Nuovo Cimento 11, 693 (1959).

b) S.M. Berman and D.A. Geffen, Nuovo Cimento 18, 1192 (1960).

c) C. Quigg and J.D. Jackson, UCRL-18487 (1968).

d) M. Pratap and J.T. Smith, Phys. Rev. D5, 2020 (1972).

It has been suggested that the high cross-section $e^+e^- \to$ hadrons observed at SPEAR, CEA and Frascati can be explained by electrons having hadronic cores. These could contribute to the decays of pseudoscalar mesons into e^+e^- pairs for which model-independent considerations[8)] show that only pseudoscalar and axial vector couplings are possible. Decay rates were then estimated in terms of the corresponding coupling constants, f_{PS} and f_A, and these demonstrated that the measurement of the $\pi^0 \to e^+e^-$ branching ratio is the most sensitive test. The published data of those experiments having large numbers of π^0's and the means of detecting e^+e^- pairs were then reviewed to obtain an upper limit on B_{π^0} of $< 8 \times 10^{-6}$. This severely limits pure pseudoscalar coupling.

Any experiment will employ a very high intensity beam of some other particle to make the π^0 within a high precision magnetic spectrometer of large solid angle. One will trigger on 2 electrons and measure their momentum and opening angle so as to construct their invariant mass; $\pi^0 \to e^+e^-$ should then show as a peak superimposed on the background of internal conversion electron-positron pairs.

Methods for copious π^0 production have been examined elsewhere in detail[9] especially with regard to competing backgrounds. Kinematically indistinguishable backgrounds can come from:

i) $\pi^0 \to e^+e^-\gamma$. With any reasonable momentum determination single Dalitz pairs with a soft photon will be negligible;

ii) Any particle combination making a π^0 can also make a γ which may then internally convert. Consider π^- capture at rest; then the low value of the Panofsky ratio, P = 1.6 gives

$$R = \frac{\pi^- p \to \pi^0 n \to e^+e^- n}{\pi^- p \to \gamma n \to e^+e^- n} = \frac{1}{30}$$

for

$$E_{e^+e^-} = m_{\pi^0} \pm 1\% \quad .$$

Extensive Monte Carlo studies show that even in the optimal case, $\pi^0 \to e^+e^-$, would give a small enhancement on an enormous background[10]. At present, only $\pi^- p \to \pi^0 n$ at 180 MeV can give several hundred $\pi^0 \to e^+e^-$ at the unitarity limit free from large backgrounds. It has the large $\sigma \approx 48$ mb since it is dominated by $\Delta(1236)$ production; background (ii) is suppressed by the favourable 0.6% partial decay fraction of $\Delta(1236) \to \gamma n$. Measuring forward angles exploits the different angular distributions of the two processes so that $R > 1$ can be expected (see Fig. 6).

3.2.2 Electron-positron pairs from stopped negative pions[11]

The yield of electron-positron pairs is expected to be about 0.5% of the radiative capture rate, this rate being about 0.03 per stopped pion for light nuclei, 0.3 for deuterium and 0.5 for hydrogen. Only a few per cent of the pairs are interesting, and others appearing at small opening angles with a momentum transfer near 140 MeV/c (carrying no more information than radiative capture, unless another particle is detected in coincidence). Over-all there should be a few interesting events per million stopped pions for light nuclei and an order of magnitude more for deuterium. Hydrogen gives a prolific yield of neutral pions and does not look very easy but is of great theoretical importance.

Judging from the existing data for the muon channel it may not be unreasonable to hope for 10^5 stops per g cm^{-2} per second in the Proton Hall. This would give an interesting event rate from a 1 g cm^{-2} target of at least some hundreds per hour distributed uniformly over the 4π solid angle. One has to measure the magnitude and direction of the momenta of electron-positron pairs, the most interesting events being those in which the momenta are similar in magnitude and nearly opposite in direction, i.e. in which the momentum transfer is small. Magnetic analysis is the only respectable method for momentum determination and it will be necessary to have a geometric acceptance of something like a double cone of half-angle 60° to avoid the exclusion from observation of some electron-positron pairs of large opening angles. Effectively this defines a large-volume magnet with wire chambers.

There could be difficulty with spiral tracks, as the range of momenta is large, say 20 to 100 MeV/c for interesting events, but the count rate is relatively high and it should be possible to resolve the problems by a series of measurements at different magnetic fields.

For nuclear structure purposes the pairs look like radiative capture at variable momentum transfer. In this case the energy resolution is important and it is likely to be limited by multiple scattering to about 1 MeV at best.

Energy loss by the electrons in the target does not appear to be a serious problem if the target is a thin slab, say about 0.1 g cm^{-2} inclined so that the beam sees 1 g cm^{-2}. Electrons emitted normally to the surface lose 0.1 MeV/c; this can be corrected if the members of the pair come out on opposite sides.

3.2.3 Radiative capture of $\pi^{\pm}$ in flight by nuclei

Radiative capture of π^- at rest by nuclei

$$\pi^- + {}^{A}_{Z}X \to {}^{A}_{Z-1}X^* + \gamma \qquad (1)$$

was proposed[12] as a tool for the study of the $T^{(3)} = T_0 + 1$ analogues $[t^{(3)} = -\frac{1}{2}$ for protons and $t^{(3)} = +\frac{1}{2}$ for neutrons$]$, of the giant dipole states of the target nucleus ${}^{A}_{Z}X$, with ground state isospin $\vec{T}_0$ and $T^{(3)} = T_0$. Due to the particular form of the effective Hamiltonian developed to describe the reaction (1) it was shown that the spin-flip components of the giant dipole resonances would be preferentially excited. The experiments carried out up to now[13] confirmed these predictions.

Experiments with stopped pions suffer from the limitation that the nuclear form factor is measured only at a fixed momentum transfer, with obvious difficulties for the comparisons with electron scattering results. A further difficulty arises from the uncertainty on the π-mesic orbit from which the capture occurs (unless the π-mesic X ray is detected in coincidence). It was pointed out[14] that these difficulties are overcome if π in flight are used to induce the reaction (1). The physical information which could be obtained from experiments with π^- in flight would be thus superior to that from stopped π^- to the same extent as electron scattering experiments are superior to nuclear photoabsorption experiments.

Furthermore, π^+ can be used, and it would be possible to study the $T^{(3)} = T_0 - 1$ analogues of the giant resonance:

$$\pi^+ + {}^A_Z X \rightarrow {}^{A}_{Z+1}X^* + \gamma \quad . \qquad (2)$$

This is of particular interest for target nuclei with ground state isospin $\vec{T}_0 \neq 0$. In the $T^{(3)} = T_0 - 1$ analogues in fact all the three components with $\vec{T} = T_0 + 1$, T_0 and $T_0 - 1$ generated by the dipole isospin operator on the ground state would show up. For T_π = 20-40 MeV differential cross-section of ∿ 20 μb/sr for excitation of each single state is expected[15].

A gold converter of the photons is placed at ∿ 15-20 cm from the target, and must have a length of ∿ 50 cm in order to cover the angular range from ∿ 40° to ∿ 130°. Since the electrons and the positrons of the pairs follow quite different trajectories corresponding to the different emission angles, it is hard to use a unique localization plane as for the usual pair spectrometers, but perhaps several planes in "strategic" positions. An efficient pair of Lucite Čerenkov counters must be placed immediately before the converter in order to accept also the events for which one of the charged particles of the pair spirals backward. This pattern occurs mainly for reactions with a photon at forward or backward angles. A considerable number of scintillators must be placed inside the magnet in order to make the trigger as clean as possible. Some lead shields could help in the rejection of unwanted triggers.

With a thickness of 0.05-0.1 mm for the gold converter, a total detection efficiency for 150 MeV photons of the order of 10^{-3} can be foreseen (∿ 10^{-2} from the conversion efficiency and ∿ 10^{-1} from the geometrical acceptance for the pairs). Assuming thus a beam intensity of 10^6 π/sec and ∿ 10 μb/sr for the differential cross-section for the excitation of the individual states of ${}^{A}_{Z-1}X^*$ (or ${}^{A}_{Z+2}X^*$) from the reaction (1) [or (2)], we could expect more than 10 events per day for each peak or complex and for each momentum band of ∿ 25 MeV/c. Since we can cover a momentum transfer region of ∿ 150 MeV/c simultaneously, the total number of events (integrated over the different momentum transfers and the excitation energies) could be 10^3 events per day. The same apparatus can be used without any physical change to study $\pi^\pm + {}^A_Z X \rightarrow {}^{A}_{Z\pm1}X^* + (e^+e^-)$. In this case the physical event rate is expected to be a factor ∿ 10^{-2} lower, but there is of course no need for a converter. Thus the experimental event rate is of the same order as for the previous experiment. The only change is in the trigger, selected to choose e^-e^+ pairs coming directly from the target.

3.3 Double charge exchange on nuclei and π^0 lifetime measurement

3.3.1 Double charge exchange

Double charge exchange reactions

$$\pi^{\pm} + (A, Z) \rightarrow \pi^{\mp} + (A, Z \pm 2)$$

represent a unique tool in studying nuclear structure; this transition changes the third component of isotopic spin by two units without changing the number of nucleons in the nucleus. This fact has no analogue in the nucleon-nucleus interaction. Information on nuclear structure can be obtained both by the study of final states and by the study of the dominant mechanism of the reaction[16]. Recognition and analysis of final states allows a study of isobaric analogue states of known nuclei (two-particle/two-hole excitations). Systematic study of double charge exchange reactions in different nuclei, for π^- and π^+ incoming, can give information on nucleon correlations, pairing and shell structure and the difference between proton and neutron distributions in nuclei.

No conclusive counter experiments exist, because the cross-sections are rather small (from 1 to 100 μb) and π fluxes have not been high enough to permit decisive measurements.

In particular there is a great uncertainty regarding the production of definite final states[17-19]; this process seems to have a forward differential cross-section of about 1 μb/sr.

In our opinion the Omicron spectrometer has the required qualities for the study of double charge exchange, reasonable resolution (about 1 MeV for π of 300 MeV/c) and a good solid angle (about 0.9 sr).

Figure 4 shows a possible set-up for a double charge exchange measurement. The incident pions are analysed in momentum by means of proportional chambers C_1, C_2, C_3, C_4, while the outgoing particles are analysed by the proportional chamber C_5 and drift chambers C_6, C_7, C_8. The magnetic field is 11 kG for a π momentum of 300 MeV/c: the trigger for the chambers is given by the coincidence $S_1S_2S_3S_4S_8A_1$. The energy resolution for pions of 300 MeV/c is about 1 MeV plus the uncertainty due to straggling in the target. With a target of 0.5 g/cm^2 of beryllium we achieve a total resolution of about 1.5 MeV. Assuming a flux of 5×10^6 π/sec on the target a detection efficiency of 100%, and a solid angle of 0.9 sr we obtain a counting rate of 1.5×10^4 events per day for each μb/sr of the differential cross-section; these features permit rather good statistics to be accumulated. The solid angle of 0.9 sr was obtained from the simulation program using the geometrical arrangement of Fig. 4.

Some problems arise in the background in view of the small cross-section. The main sources are:

i) elastic and inelastic scattering of pions;

ii) electrons and positrons produced by γ-rays due to the decay of π^0 generated in the target by simple charge exchange reactions.

The first source of background produces a great number of spurious triggers and must be rejected with some form of fast hardware analysis. A fast (some μsec) recognition of the sign of the curvature of the trajectory seems to be necessary. This could be done by a single comparison between the horizontal coordinates of chambers C_5, C_6, C_8. The time needed for processing signals from chambers could be of the order of 1 μsec, while the total time for recognizing the sign of the curvature depends on the distance between the wires in the drift chambers and on the read-out system of the chamber; a value of some tens of μsec seems to be reasonable. In any case, spurious triggers of this type do not constitute a real background for the experiment, because they are easily recognizable in the off-line analysis. The second source of background would be considerably lowered using a range detector after the last chamber in the spectrometer.

3.3.2 π^0 lifetime measurement

It is perhaps a surprising fact that the π^0 lifetime is not very well known. However, various quark theories make absolute predictions of its value and consequently it is desirable to know this lifetime more precisely; a measurement to 5% would be adequate.

The first measurement was made in emulsion using the reaction $K^+ \to \pi^+ + \pi^0$ followed by $\pi^0 \to e^+e^-\gamma$. The limitation was the grain size of the emulsion, since the π^0 actually travelled a good deal less than this grain size before decaying. Another measurement used the photoproduction of π^0 in the Coulomb field of lead, for which the production cross-section is inversely proportional to the π^0 lifetime. The best measurement so far, however, determined the lifetime by counting the e^+ produced from the decay γ-rays converting in platinum (used both as production target and converter). This e^+ flux varied with platinum thickness and the authors were able to deduce the π^0 lifetime.

The present proposal is to use the reaction $\pi^-p \to \pi^0 n$ followed by $\pi^0 p \to \pi^+ n$. That is, the π^0 is made to undergo a charge exchange reaction following its production in the liquid H_2 target; this takes place of course within a distance of a few times 10^{-6} cm, but nevertheless the cross-sections are such that count rates of the order of tens per hour might be expected for the π^+ produced. Note that the incident beam is π^- (at the 3,3 resonance) and the particle sought is a π^+: thus the experimental arrangement is very similar to the double charge exchange geometry proposed for Omicron.

In order to deduce the π^0 lifetime, the absolute cross-sections for the reactions involved must be known (which they are), and the energy and direction of the emitted π^+ must be measured. The main problem is the background of π^+ caused by γ-rays through the reactions $\pi^- p \to \gamma n$, followed by $\gamma p \to \pi^+ n$. This is very similar kinematically to the reactions of interest and in fact causes an event rate which is of approximately the same size as the real π^+ rate. There are also γ-rays from π^0 decay, causing $\gamma p \to \pi^+ n$ events, and these too will cause some problems, except in the forward direction where they are clearly distinguishable kinematically. Other possible reactions involving the protons or neutrons knocked on do not interfere, being unable to yield π^+ of anything like the right energy; the same goes for electrons via the $e^- p$ interaction.

3.4 ($\pi^\pm$, $\pi^\pm p$) reactions on nuclei

The main interest in the study of these reactions on some selected nuclei (e.g. ^{12}C, ^{16}O) is related to the π^+/π^- ratio puzzle found some years ago in measurements by the activation technique[20]. Among different hypotheses raised to explain the experimental ratio of 1, the most reasonable seems that the production of ^{11}C, ^{15}O nuclei is related to a de-excitation of highly excited states in ^{12}C, ^{16}O. The total isospin $\vec{T}$ of the intermediate states plays a crucial role. If only $\vec{T} = 0$ states were involved, the production of ^{11}C, ^{15}O would proceed only through the excitation of these states, and we will get immediately the ratio 1. If, on the contrary, $\vec{T} = 1$ states were essentially involved, we must admit a nearly equal contribution from the mechanisms of quasi-elastic scattering and intermediate state reaction. A measurement of the absolute cross-sections for ($\pi^\pm$, $\pi^\pm p$) reactions leading to the ground states of ^{11}C, ^{15}O, would give a definite answer to the puzzle. More recent measurements have been made with a propane bubble chamber and consequently poor energy resolution and statistics[21]. With the Omicron spectrometer an energy resolution of $\sim$ 1 MeV could be attained with high counting rates due to the large cross-sections expected for the reaction (some mb/sr).

4. TIME SCALE

Preliminary estimates of the time required for various parts of the construction work, excluding the mounting of apparatus specific to our experiment, are given in Table 4. The limiting items are the manufacture of the new poles for the magnet (if Liverpool steel plate is not available), the development and manufacture of drift chambers, and on-line software if the delivery of the small computer is delayed. It is supposed that the off-line programing is in the nature of a continuing development. Another possible problem might be the fitting-in of the necessary work in the Proton Hall with the general SC program.

It would be reasonable to expect that the manufacture and assembly of the spectrometer, ready for mounting an experiment, will be complete by the summer of 1976.

Table 4

Time scale

	Estimated time in months or completed date
Magnet	
Computing of magnet modifications	2
Design of pole pieces and yoke modifications	1
Manufacture of new poles and yoke spacer	
- new material	9 ± 3
- Liverpool steel plate	3
Transport to CERN	2
Assembly of magnet in pit	1
Survey of magnetic field and modifying of shims	2
Magnet box	
Design of framework and rails	1
Manufacture of framework and rails	3
Design of panels and entry parts for cables and light guides	1
Manufacture	3
Transport to CERN	1
Assembly and alignment of internal and external rails	1

./...

Table 4 (cont.)

	Estimated time in months or completed date
Emplacement	
Decision on exact location via detailed calculations of beams	4
Design of pit, base plate and bearing fixing	1
Construction of pit	2
Manufacture of base plate	1
Delivery of bearing	3
Provision of services	1
Wire and drift chambers	
Prototype MWPC with 1 mm spacing	Dec. 1974
Decision on pre-amplifiers and mechanics	April 1975
Manufacture of MWPCs	Oct. 1975
Testing of prototype MWPC	April 1975
Prototype drift chamber	Feb. 1975
Beam tests of prototype drift chamber	Sept. 1975
Manufacture of drift chambers	Dec. 1975
Delivery of wire/drift chamber electronics	∿ 6
Assembly of wire/drift chamber electronics	∿ 6
Computers	
Delivery of Nord 10	? 6
Software for on-line computing	12 +
Software for off-line computing	12 +
Beams	
Manufacture of DISC	6
Design of beams	6
Manufacture of vacuum pipes	1
Assembly	1
Investigation of beam properties	1

5. DISPOSITION OF MANPOWER DURING THE CONSTRUCTION PERIOD

5.1 Magnet and magnet box

Two physicists (Tanner, Davies);
One design engineer and workshop facilities at Oxford.

(It is hoped to obtain from RHEL the advice of their engineers with regard to design, and the assistance of W. Trowbridge et al., with the computer calculations).

5.2 Emplacement

CERN SB Division under the direction of MSC engineers in consultation with an SC physicist (Allardyce).

5.3 Wire and drift chambers

Three and a half physicists (Bressani, Chiavassa, Cocta, half Musso) plus technicians and workshop facilities in Turin. Other contributions to be decided (Van Dantzig from IKO, Amsterdam).

5.4 Electronics for wire and drift chambers

2 × ½ physicist for ½ year for decisions, buying and testing (Bonazzola and Musso), 1 technician from Turin for ½ year for assembly.

5.5 Beams

3 × ½ physicist (Allardyce, Bajon, Salmon) for ½ year for beam design. Other contributions to be finalized (probable IKO Amsterdam participation). DISC manufacture in Amsterdam (Arnold, Van Dantzig).

5.6 On-line software

1 NP Division programmer.

3 × ½ physicist at CERN (Dellacasa, Pasqualini, Ferrero).

5.7 Off-line software

2 DD Division programmers;
1½ physicists (Gallio, Dellacasa).

Other contributions to be decided (Van Dantzig, Amsterdam).

6. FINANCIAL IMPLICATIONS

The two biggest items, i.e. the magnet and its power supply, are excluded from consideration as it is hoped to obtain these on loan from RHEL and CERN, respectively and it is not easy to assign a value. Various other items which can be manufactured at the laboratories of the participating members are included, but are placed in a separate column. The cost of beam elements, off-line computing, scintillation and chamber counters, targets, and trigger (nsec) electronics have been excluded.

The total of the permanent equipment is estimated to be Sw. Fr. 1,224,000 of which about Sw. Fr. 348,000 can be provided by home institutions of the Collaboration mostly in the form of manufacturing effort. The shortfall of Sw. Fr. 876,000 is requested as the support from CERN. To this it would be proper to add the implicit load that will fall on the engineering and computer services at CERN which, at least for some time ahead, is estimated to be equivalent to two programmers, one technician and a fraction of an engineer.

The situation is summarized in Table 5.

Table 5

Cost of permanent equipment

	All items (in thousands of Sw. Fr.)	Requested from CERN	Contribution by home institutions
Computer			
Nord 10 central processor unit	42		
Real-time clock	2		
Memory, 32K	47		
CAMAC and DMA	14		
Disk controller and 4 cartridges	19		
Magnetic tape transport	39		
Card reader	22		
Teletype	9		
Display terminal	22		
Plotter/Printer	60		
	276		
Less CERN discount 8%	-22		
Net	254	254	

./...

Table 5 (cont.)

	All items (in thousands of Sw. Fr.)	Requested from CERN	Contribution by home institutions
Wire chambers			
MWPC, construction and development (commercial price)	60		60
MWPC electronics, 1500 wires at Sw. Fr. 100/wire made up of the standard Sw. Fr. 80/wire plus power supplies and interface	150	150	
Drift chamber construction and development (commerical price)	120		120
Drift chamber electronics for 150 wires at Sw. Fr. 300/wire	45	45	
	375	195	180
Magnet			
Transport RHEL to CERN (quotation)	35		
Return to RHEL	35		
New poles (cast and machined, about Sw. Fr. 80,000. Fabricated from Liverpool steel plate Sw. Fr. 60,000)	70 ± 10		
Modifications to yoke	15		
NMR	20		
Hall plates	7		
	182	182	
Magnet box			
Framework	13		
Rails and fixings within magnet	18		
External rails	7		
Panels for helium seal	10		
	48		48
Emplacement			
Pit 4.8 m diameter	55		
Base plate	15		
Slewing ring (bearing)	15		
	85	85	

./...

Table 5 (cont.)

	All items (in thousands) of Sw. Fr.)	Requested from CERN	Contribution by home institutions
Cryogenic refrigerator	60	60	
DISC	120		120
Total	1,124	776	348
To which must be added a sum for assembly and provision of services	∿ 100	∿ 100	
Grand total	1,224	876	348

REFERENCES

1) N. Tanner, PH III-74/41.

2) B. Allardyce et al., PH III-72/2.

3) C. Cox et al., PH III-73/16.

4) A. Breskin, G. Charpak, F. Sauli and J.C. Santiard, Nuclear Instrum. Methods 119, 1 (1974).

5) A. Breskin, G. Charpak, B. Gabioud, F. Sauli, N. Trautner, W. Duinker and G. Schultz, Nuclear Instrum. Methods 119, 9 (1974).

6) J. Lindsay, CERN 74-12 (1974).

7) J. Beiner and P. Huguenin, Helv. Phys. Acta 42, 550 (1969).

8) H. Burkhardt, R.K.P. Zia and J.D. Davies, J. Phys. A7, 40 (1974).

9) J.D. Davies, J.G. Guy and R.K.P. Zia, RHEL RI-74-092 (to be published in Nuovo Cimento).

10) W.P. Trower, private communication.

11) Letter of Intent, PH III-74/29.

12) J. Delorme and T.E.O. Ericson, Phys. Letters 21, 98 (1966).

13) H.W. Baer and K. Crowe, Proc. Int. Conf. on Photonuclear Reactions and Applications, Asilomar (1973) p. 583.

14) T. Bressani, Riv. Nuovo Cimento 1, 268 (1971).

15) F. Cannata, B.A. Larners, C.W. Lucas, A. Nagle, H. Überall and C. Werntz, preprint, 1973.

16) F. Becker and Y.A. Batusov, Riv. Nuovo Cimento 1, 309 (1971).

17) L. Gilly, M. Jean, R. Meunier, M. Spighel, J.P. Stroot, P. Duteil and A. Rode, Phys. Letters 11, 244 (1964).

18) P.E. Boynton, T. Delvin, J. Solomon and V. Perez-Mendez, Phys. Rev. 174, 1083 (1968).

19) C.J. Cook, M.E. Nordberg, Jr. and R.L. Burman, Phys. Rev. 174, 1374 (1968).

20) D. Chivers et al., Nuclear Phys. 126 A, 129 (1969).

21) E. Bellotti et al., Nuovo Cimento 14 A, 567 (1973).

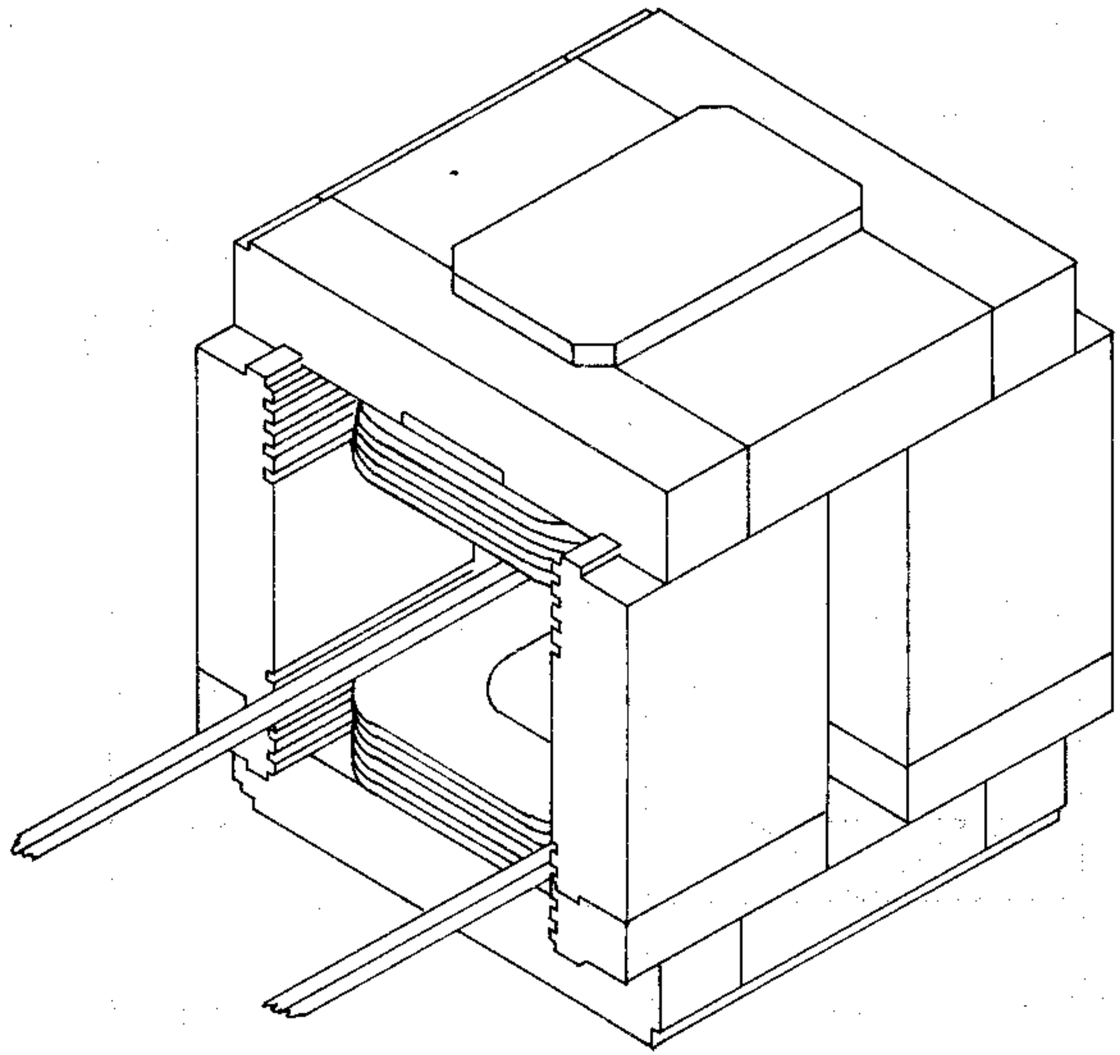


Fig. 1

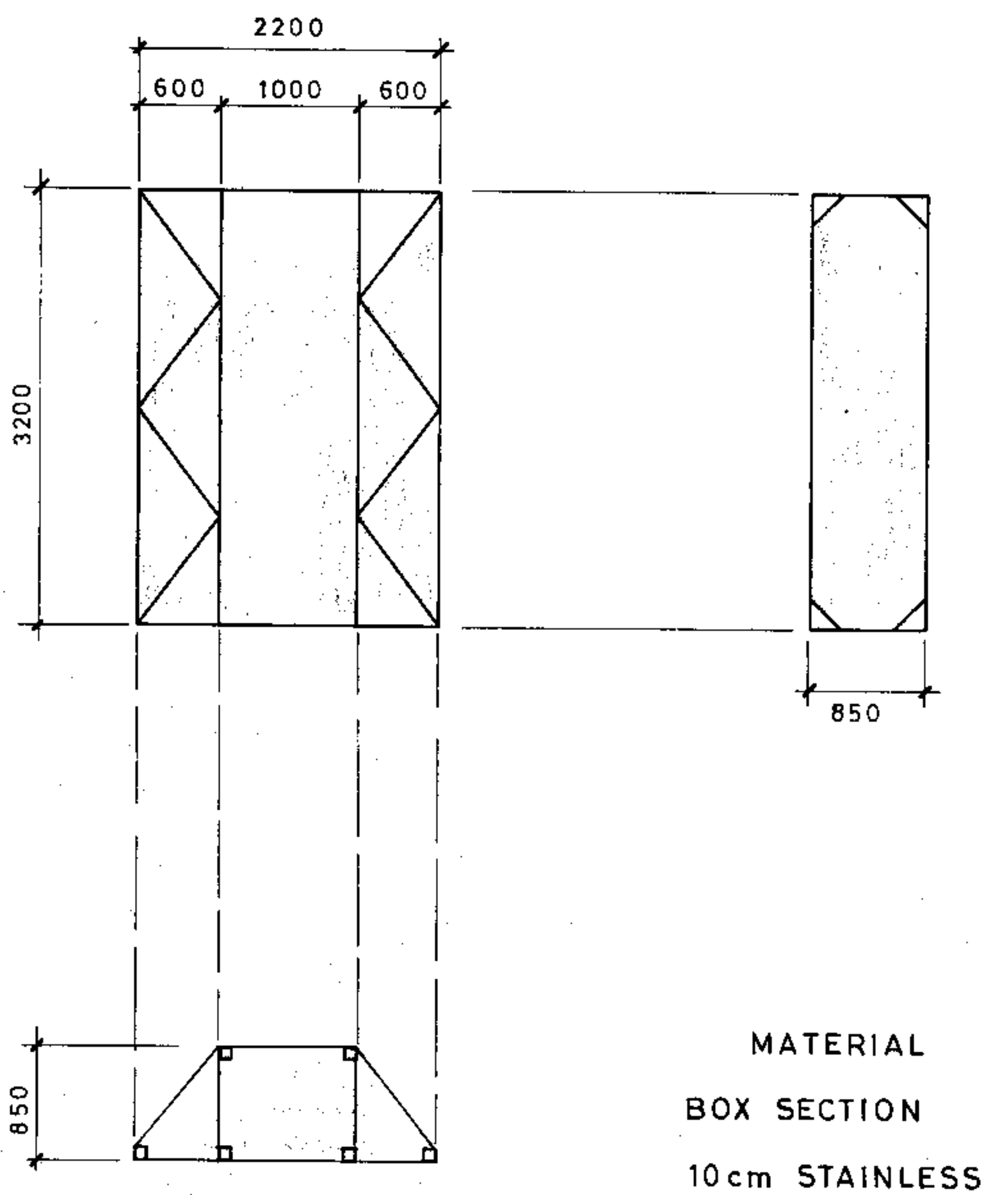


Fig. 2 Framework to fit inside M11 magnet

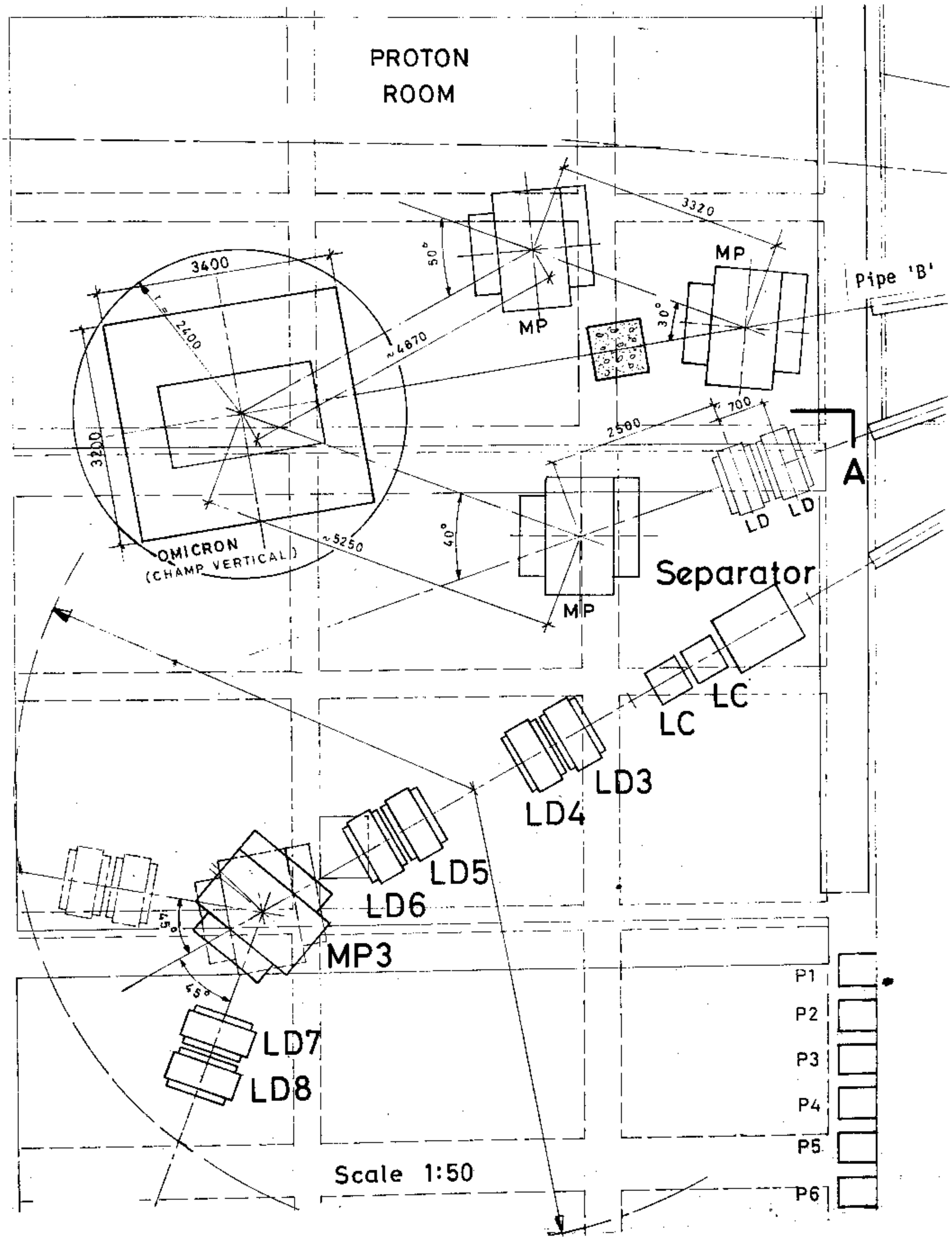
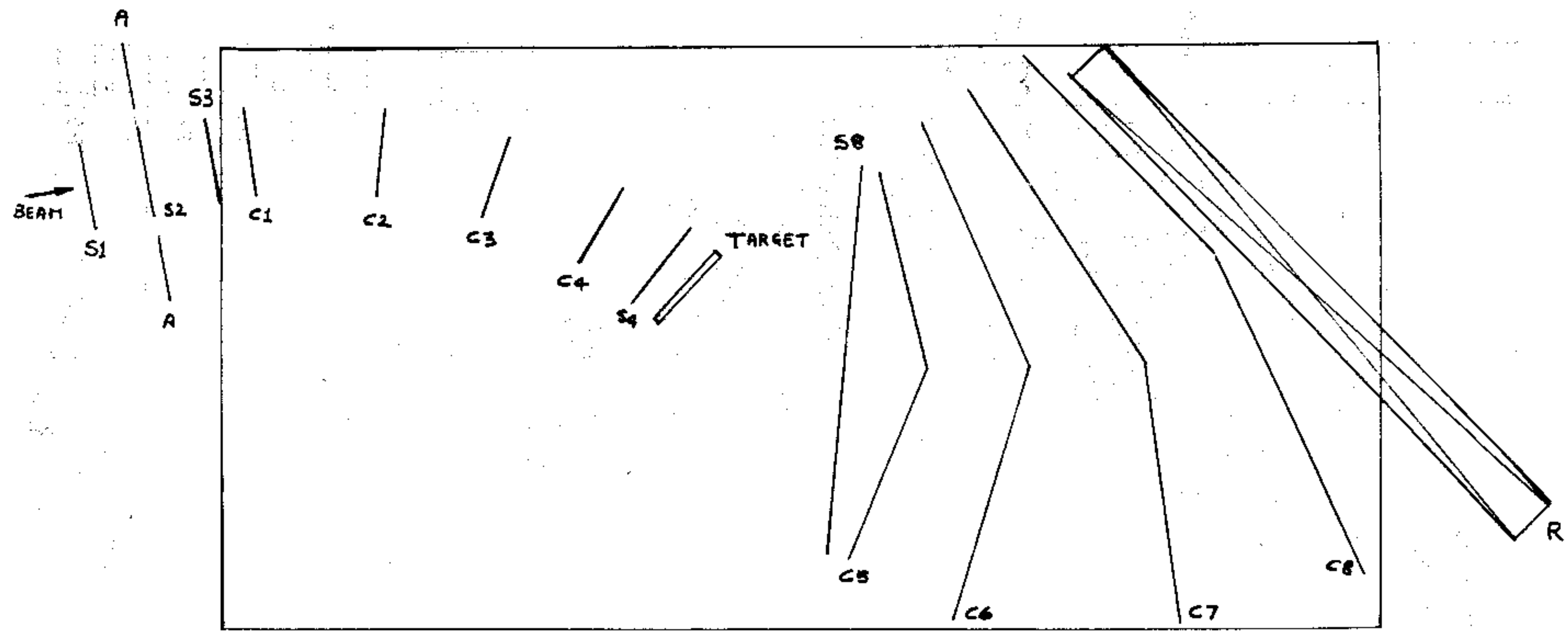

PROTON
ROOM
3320
MP
Pipe 'B'
50°
30°
MP
3400
r = 2400
~4870
700
2500
3200
A
LD
LD
40°
OMICRON
(CHAMP VERTICAL)
~5250
Separator
MP
LC
LC
LD3
LD4
LD5
LD6
45°
MP3
45°
LD7
LD8
P1
P2
P3
P4
P5
P6
Scale 1:50

Fig. 3



MWPC	COUNTING PLANES
C1	XYU
C2	XY
C3	X
C4	XYU
C5	XYU
DRIFT CH.	
C6	XY
C7	X
C8	XYU

A1 ———

T : TARGET
S1, S2, S3, S4, S8, A, A1 : SCINTILLATORS
R : RANGE ARRAY

Fig. 4 Layout for double charge exchange experiment

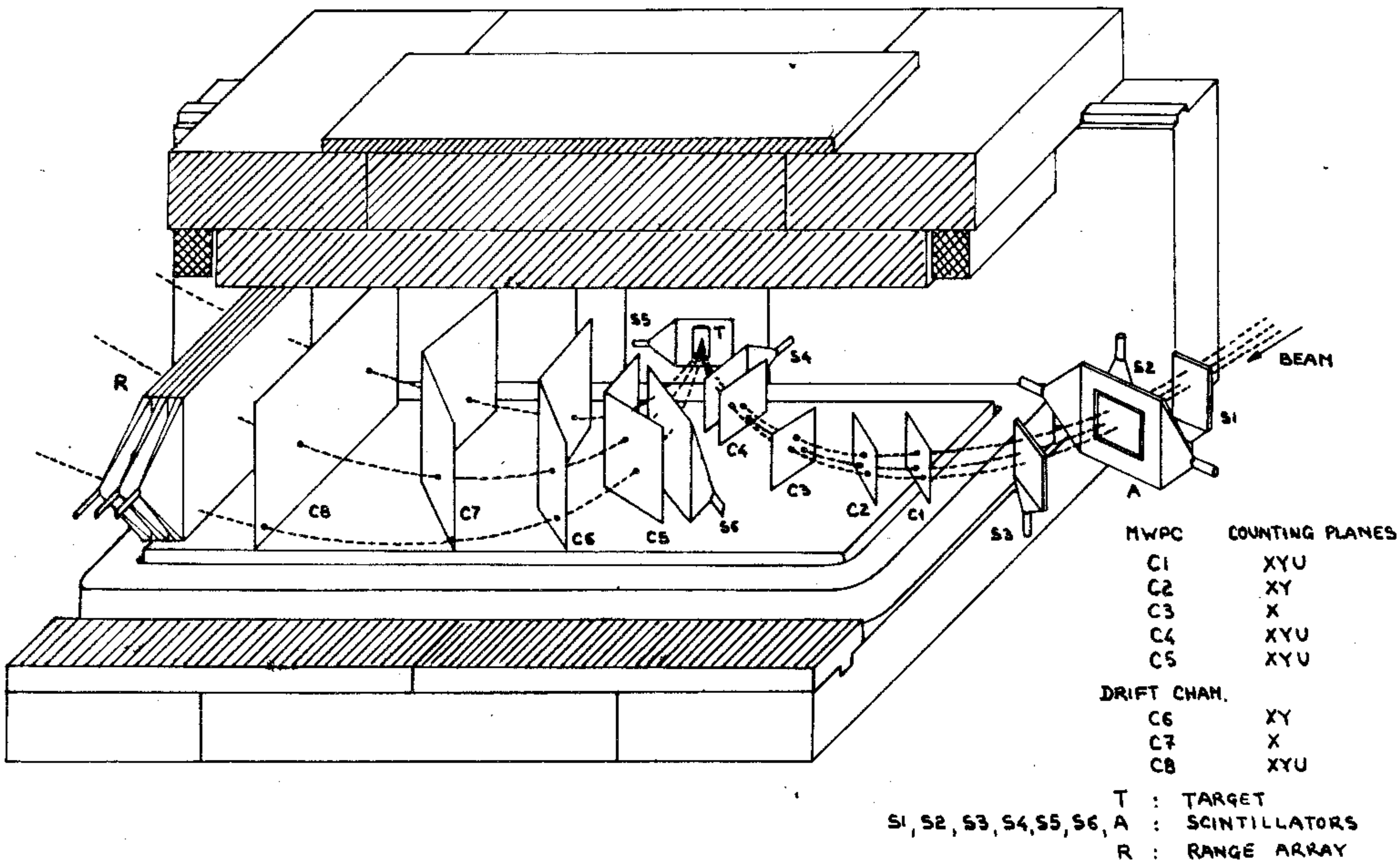


Fig. 5 Muon scattering experiment

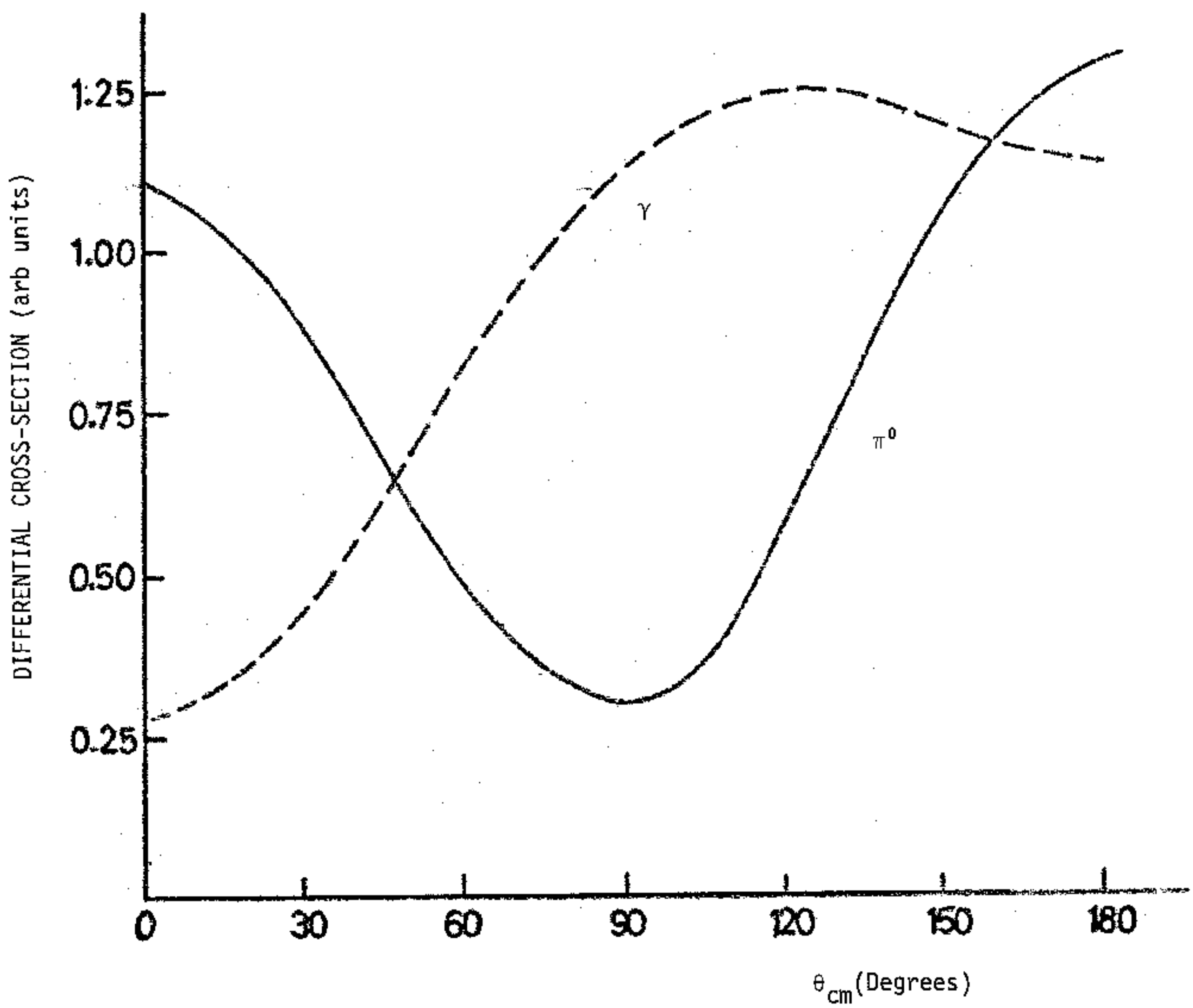


Fig. 6 The angular distributions of photo-emission ($\pi^- p \to \gamma n$) and charge-exchange ($\pi^- p \to \pi^0 n$) processes at T_π = 180 MeV