THE RUTHERFORD HIGH ENERGY LABORATORY

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1. GENERAL

On 14 February 1957 the British Government announced in the House of Commons its decision to set up the National Institute for Research in Nuclear Science. The main object of the Institute was "to provide for common use by universities and others, facilities and equipment which are beyond the scope of individual universities and institutions carrying out research in the nuclear field".

The Rutherford High Energy Laboratory was the Institute's first laboratory. Dr T G Pickavance was its first Director. He was charged with the task of building the 7 GeV proton synchrotron - Nimrod - which was to be the Laboratory's principal research facility. In February 1964 the first scheduled experiments ran on Nimrod. In 1965 the National Institute for Research in Nuclear Science ceased to exist and the Rutherford Laboratory became part of the Science Research Council. However, the purpose for which the National Institute for Research in Nuclear Science was founded, namely to operate a large research facility for the general benefit of Universities, remained the guiding principle.

University scientists are closely involved in all the Laboratory's affairs. This involvement is strengthened by the policy adopted to finance the experimental work Final approval for an experiment by any team is given by the Experiments Selection Panel, which is composed not only of physicists from within the Laboratory, but also, and predominantly, from the universities. Once an experiment is on its programme, the Rutherford Laboratory accepts the responsibility to provide all the necessary funds to carry out the experiment. Funds are made available in several ways. For work which the University wishes to carry out at home, an agreement is drawn up whereby the Laboratory refunds the expenses of the University on that particular work. In addition, the team is given an allocation of money from the High Energy Physics Division budget for

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use at the Rutherford Laboratory. The resources of the Laboratory are fully at the University scientist's disposal on exact parity with members of the Rutherford Laboratory staff. The Laboratory provides houses and hostel accommodation for visitors and it reimburses them for travelling and other incidental expenses incurred when visiting the Laboratory. We now adopt a similar policy for the support of British scientists using CERN. Once the experiment has been accepted on to the Laboratory programme and approved by the CERN nuclear physics research committee, we undertake to provide whatever equipment cannot be provided by CERN as well as the funds for travel to CERN and for living in Geneva.

2. LOCATION

The Rutherford Laboratory is situated at Chilton in Berkshire, about 15 miles from Oxford. It is about 60 miles from London. There are frequent fast train to and from London and a motorway connects it to London Airport which can be reached by car within the hour.

3. ORGANIZATION

The Laboratory supports about 200 university physicists who work either on Nimrod or at CERN. It has its own high energy counter and bubble chamber physicists, but the number is kept deliberately low, so that up to 80% of the high energy research may be done by physicists who have university appointments. The total Laboratory complement is 1200. Functionally, the Laboratory is divided into seven Divisions, namely:-

(a) High Energy Physics:	Head and Deputy Director - G Manning
(b) Nimrod:	Head - D A Gray
(c) Computing and Automation:	Head - W Walkinshaw
(d) Theory:	Head - R J N Phillips
(e) Applied Physics:	Head - D B Thomas
(f) Engineering:	Head and Chief Engineer - P Bowles
(g) Administration:	Head and Laboratory Secretary - J M Valentine

In addition to the operation of Nimrod and the direct support of the high energy physics experimental programme on Nimrod, the Laboratory provides all the resources needed by the affiliated University teams to mount experiments at CERN.

In practice about half of the High Energy Physics Division funds go towards the support of CERN experiments. The high energy physics programme is supported by extensive computing and data analysis facilities and there is an applied physics programme aimed at the longer term needs of high energy physics. This work is described in more detail below where I shall attempt as much as possible to show how the Rutherford Laboratory programme links up with CERN.

4. HIGH ENERGY PHYSICS

4.1. Nimrod

Figures 1 and 2 show the present layout of beams in the three experimental halls of Nimrod. There are a total of four counter beams derived from internal targets and six from two extracted beams. One of these extracted beams (X2) has a single target feeding two beams and the second (X3) has two sequential targets each feeding two counter beams. A low energy pion irradiation beam (π11) is also derived from one of these targets. A third extracted proton beam (X1) feeds a separated beam for the 150 cm hydrogen bubble chamber.

A short spill in X1 for the bubble chamber followed by a long spill for the counters, in either X2 or X3, can be given on the same flat top. Similarly a short spill for parasitic setting-up can be given during current rise, in X2 prior to a long spill in X3 (or vice versa). All internal beams can be fed in parallel with the extracted proton beams. This is an example of the flexible beam arrangements which are possible on Nimrod. It enables many teams to be scheduled to run together and this permits teams to undertake systematic measurements demanding long machine runs or precision experiments which require ample time for the investigation of possible systematic errors.

Table I summmarises the operation of Nimrod since its start-up. If there was the demand more experimental teams could easily be accommodated on Nimrod. At present it would be possible to provide up to about 3000 hours in one year if a team needed the time.

The most up to date extraction system on Nimrod, that feeding Hall 3, gives 1.3×10^{12} protons per pulse at the two external target stations in the Hall. Modifications are in hand to improve the two external beams in Hall 1 up to the same standard. Additional minor improvements to the accelerator are expected to yield 2×10^{12} extracted protons per pulse in 1973. The

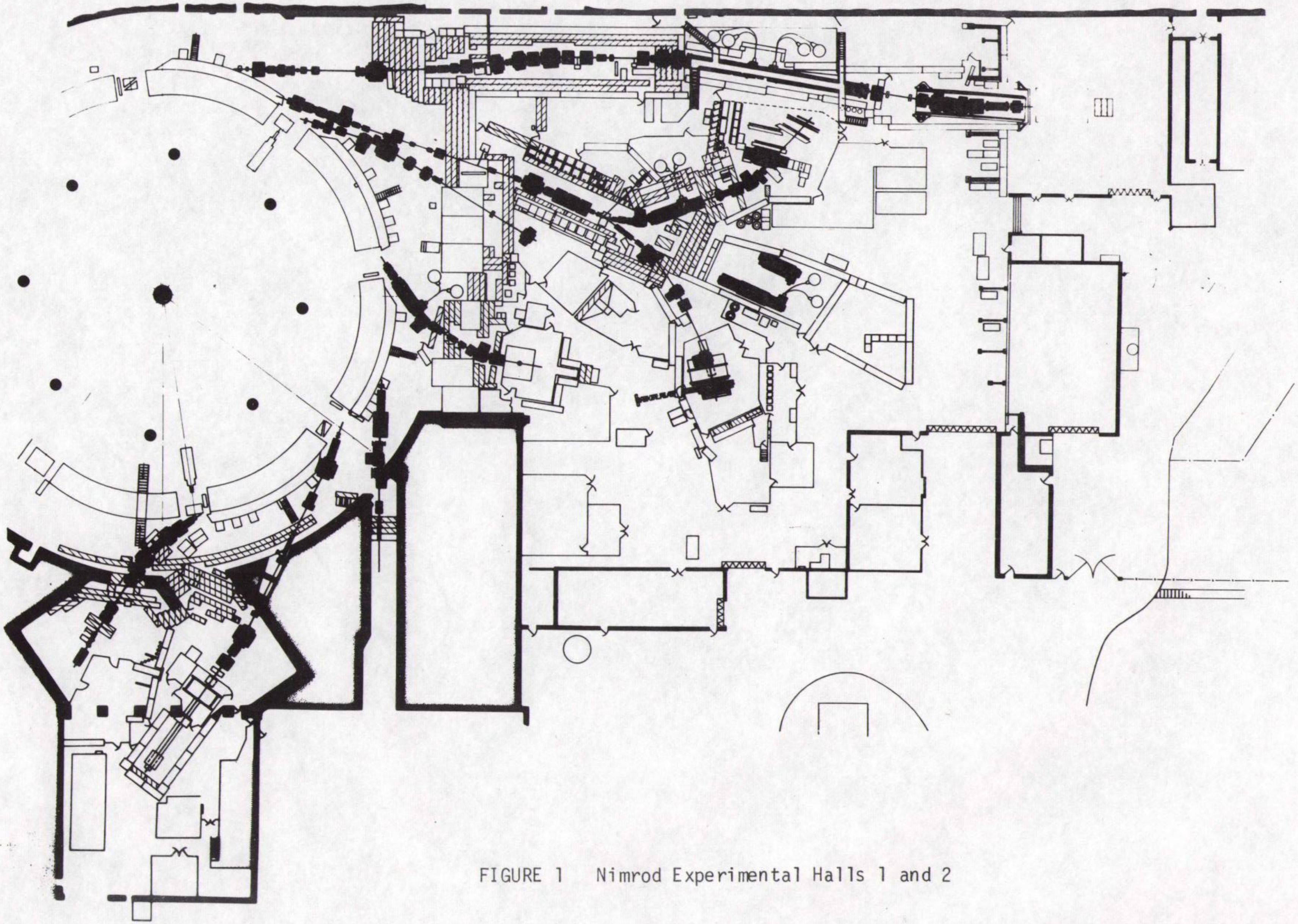

FIGURE 1 Nimrod Experimental Halls 1 and 2

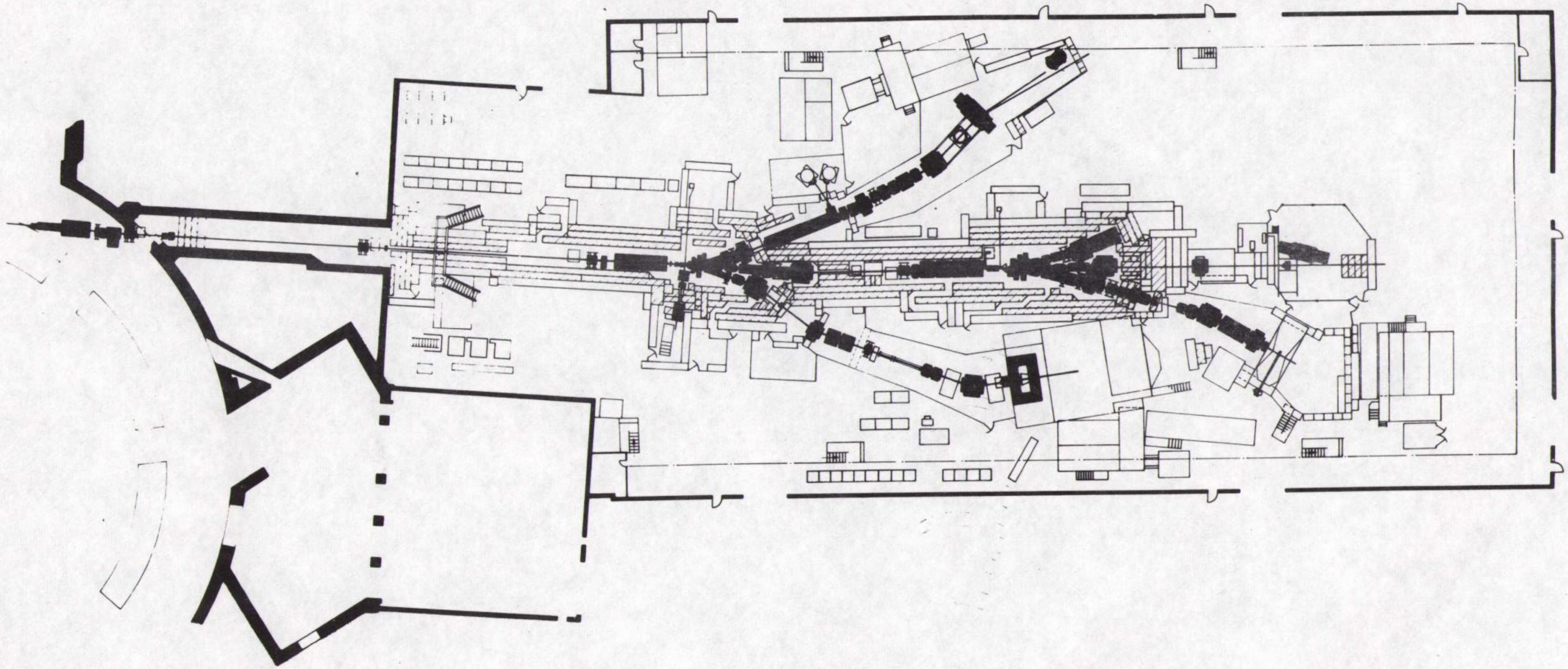

FIGURE 2   Nimrod Experimental Hall 3

TABLE 1

BRIEF OPERATIONAL SUMMARY FOR NIMROD

Period	Hrs at 7GeV for high energy physics Scheduled	Achieved	Efficiency	Total of hrs at 7GeV used by experimental teams	Average no of experiments running simultaneously	Total no of accelerated protons	Notes
1.10.64 to 31.12.65	1770	1330	75%	2811	2.1	1.67×10^{18}	7GeV operation for $\sim 4\frac{1}{2}$ months of period only
11.1.66 to 31.12.66	5840	4850	83%	18906	3.9	7.63×10^{18}	
1.1.67 to 31.12.67	4758	3723	78%	10705	2.9	5.88×10^{18}	7GeV operation for ~ 9 months of period only
1.1.68 to 31.12.68	6152	5170	84%	24907	4.8	7.19×10^{18}	~ 7 months of period at half normal repetition rate
1.1.69 to 31.12.69	5145	4521	88%	26044	5.8	1.04×10^{19}	
1.1.70 to 31.12.70	5297	4708	89%	21429	4.6	1.29×10^{19}	Totals include time at 5 & 6 GeV, at the experimental teams' request
1.1.71 to 31.13.71.	6010	4859	81%	18423	3.8	1.74×10^{19}	ditto

secondary beam intensities which will then be available are given in Figure 3. In addition to 8 GeV/c protons Nimrod will then provide adequate beams of pions up to 5 or 6 GeV/c and kaons up to 3.5 to 4 GeV/c.

4.2. Physics in the Nimrod Energy Range*

4.2.1. Strong Interaction Physics

In the Nimrod energy range there is a great wealth of physics awaiting exploration and understanding. In meson-baryon scattering, for example, the crucial questions are the systematics of baryon resonances, the nature of duality and the structure of high energy exchange mechanisms. All these can be clarified by detailed amplitude analysis at low and medium energies. Surprisingly only in the case of the pion-nucleon system has a systematic study of elastic scattering and polarization effects been completed up to about 2 GeV/c and the results have proved extremely rewarding. The detailed picture of (πN) resonances has had a profound effect on our ideas about baryon spectroscopy. Furthermore the use of finite energy sum rules has exploited the low-enery amplitude analysis to reveal unexpected properties of high energy (πN) amplitudes. Results of comparable quality are still needed for other elastic and inelastic two-body channels. Detailed amplitude analysis should then disclose important features of baryon resonances such as their spin and parity, branching ratios and symmetry properties. And through finite energy sum rules this should lead to an understanding of important properties of high energy amplitudes.

Our knowledge of the kaon-nucleon system is in a much less satisfactory state even than the pion-nucleon system, but it is no less important.

There is also still a need to extend the detailed type of amplitude analysis work through the medium energy range up to about 4 GeV/c. This is the overlap region where the low energy resonance mechanisms co-exist with high energy exchange mechanisms and where ideas of local duality between the different mechanisms can be tested directly.

Meson-baryon scattering to multiparticle final states is also a potential source of much valuable information: on inelasticities, on branching

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* A more detailed account of the physics accessible to Nimrod will be found in:
RHEL/M/C8 - A Case for Medium Energy Hadron Physics - D Morgan et al
RHEL/M/H7 - An Experimental Programme for the Nimrod Accelerator - R M Brown et al

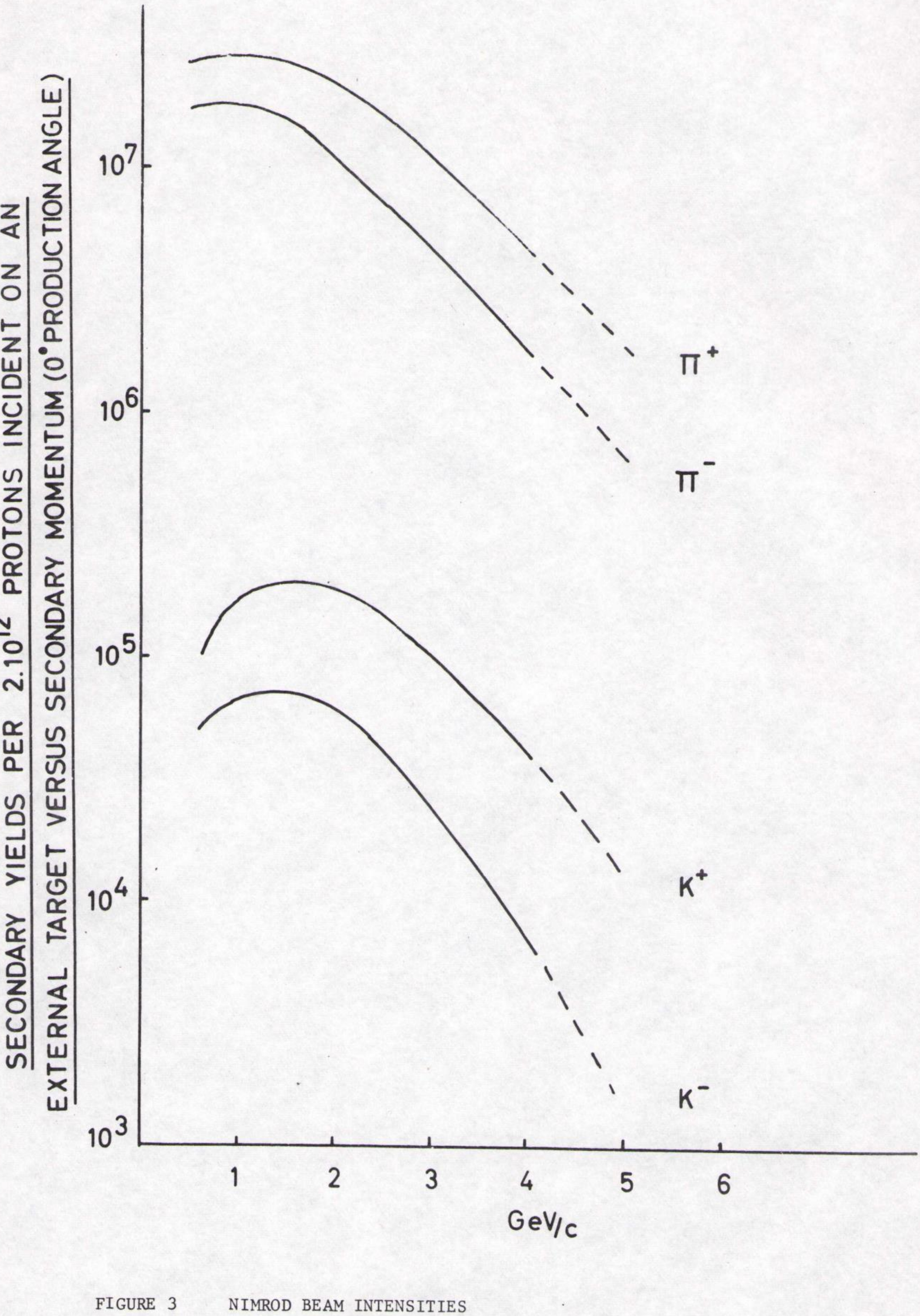


FIGURE 3 NIMROD BEAM INTENSITIES

Note that these are yields derived from a number of idealized beam designs and give yields at the experiment. In practice compromises in practical layouts would probably reduce these figures by up to a factor 5.

ratios (for symmetry checks) and on high spin baryons (predicted by linear Regge trajectories and the Veneziano model). There is, however, a lack of good data.

Paralleling the baryon spectroscopy described above,there is, of course, the equally important field of boson spectroscopy. Finding and classifying the meson states remains a major field of discovery and although most of our knowledge in this field has in the past come from bubble chamber experiments, in the future high precision selective counter experiments will be likely to play a more significant role. This is a field accessible to Nimrod.

The fundamental significance of particle spectroscopy was stressed by Dalitz at the Pennsylvania Conference on Meson Spectroscopy in 1968:

> "It is not just a question of collecting new resonances and classifying them in the spirit of zoology; in order to recognise and to establish firmly the patterns of these mesonic states, we need to know the picture completely. Together with the corresponding work with baryons these empirical studies offer the clearest route to an understanding of the internal structure of the hadrons and of the nature of the super-strong interactions which give rise to them."

This view remains true in 1972. The bulk of the work on Nimrod over the next five years will revolve around detailed studies of known phenomena in the strong interaction field. However, about 20% of the research on Nimrod has been devoted to a study of the weak interaction. Some comments on future possibilities are given in the next section.

4.2.2. Weak Interaction Physics

Although there exists a well developed theory of the weak interaction our understanding in fact remains surprisingly shallow. This is aggravated by the fact that the available experimental results on specific tests of the theory are at best in poor agreement and frequently completely in conflict. To some extent this is due to the fact that the experiments are exceedingly difficult requiring the observation of rare processes and a careful investigation of possible systematic errors. Examples of problems which remain to be investigated are CP violation, the anomalous $K_L \rightarrow \mu^+\mu^-$ rate, the $\Delta S = \Delta Q$ rule and so on. Clearly this is an area which can be well studied on Nimrod. The programme is long and difficult and will require uninterrupted painstaking work.

In Tables 2 - 4 the present world data is compared over a range of weak interaction experiments and an estimate is made of the improvement that could be obtained assuming no improvement to Nimrod beams. As mentioned above the difficulties lie less with statistics than with a careful analysis of systematic errors.

4.3. Summary of the Nimrod Experimental Programme

Tables 5 - 7 list the experiments carried out on Nimrod and still under analysis, those currently being run and those planned in the immediate future. In Table 8 an estimate is made of the percentage time devoted to particular fields of study. The study of pion-nucleon scattering alone has occupied 24% of Nimrod time ($7\frac{1}{2}$ team-years out of a total of 31).

The experimental results will not be discussed in detail in this paper. However, to give some idea of what has been achieved I will quote results from two experiments. Figure 4 shows typical polarisation measurements at two momenta in an experiment by a Rutherford Laboratory/Oxford University Group which covered the momentum range 0.6 to 2.6 GeV/c in approximately 2% momentum stops.

Figure 5 shows results by a Bristol University/Southampton University collaboration in which $K^{+}p$ elastic scattering was studied at 17 momenta in the range from 0.9 to 1.9 GeV/c.

Whereas in the past a large fraction of the Nimrod programme has concentrated on a study of pion-nucleon elastic scattering and polarisation studies, during the last year effort has moved to a study of the KN system. Emphasis is also now turning to inelastic channels in both πN and KN channels. Many higher mass baryon resonances are known to be highly inelastic and hence a study of inelastic scattering to an accuracy comparable with the elastic studies should be a productive line of research. The work will provide a completely independent analysis of the resonances and if states of the same mass, width and quantum numbers be found as those from elastic reactions, it will give added confidence in the significance and uniqueness of the interpretation of phase shift analyses. The additional information on branching ratios will give further crucial tests too on theories such as quark models, SU3 models and Regge models. In final states involving hyperons, a single experiment gives information on differential cross-sections and polarisation and an obvious development for the future is to use polarised targets to yield A and R parameters.

TABLE 2

Charged K decays

Experiment	World data	Possible data from Nimrod expt.	Possible improvement factor
$K^+ \to e^+ \nu$ limit on pseudo scaler current	88	3000	34
$K^+ \to e^+ \nu\gamma$ E-M effects	0	600	-
$K^+ \to \pi^o e^+ \nu$ form factors	10^4	4×10^6	400
$K^+ \to \pi^+ \nu\bar{\nu}$ neutral currents	BR $< 1.2\text{x}10^{-6}$	$< 8\text{x}10^{-8}$	15
$K^+ \to \pi^+ \gamma\gamma$ E-M effects	BR $< 0.4\text{x}10^{-4}$	$< 1.6\text{x}10^{-7}$	25
$K^+ \to \pi^+ \pi^- e^+ \nu$ form factors and $\pi\pi$ interaction	~ 2000	~ 8000	4
$K^+ \to \pi^+ \pi^- e^- \nu$ $\Delta S = \Delta Q$	BR $< 0.7\text{x}10^{-7}$	$< 10^{-8}$	7

TABLE 3

Neutral K decays

Experiment	World data	Possible data from Nimrod expt.	Possible improvement factor
$K_L \to \mu^+ \mu^-$	BR $< 1.6\text{x}10^{-9}$	BR $< 1.6\text{x}10^{-10}$	10
$K_L \to \pi \ell \nu$ form factors	$\sim 10^5$	$\gtrsim 10^6$	$\gtrsim 10$
$K_L \to \pi^+ \pi^- \pi^o$ $\Delta I = \frac{1}{2}$ rule	$\sim 5\text{x}10^4$	$\gtrsim 10^6$	$\gtrsim 20$
$K_L \to Ke\nu$ Test of CVC	-	~ 100	-

TABLE 4

Hyperon beta decays

Experiment	World data	Possible data from Nimrod expt.	Possible improvement factor
$\Sigma^- \to n e^- \nu$ $\frac{g_A}{g_V}$	accuracy on g_A/g_V ~ 0.2	~ 0.025	8
$\Lambda \to p e^- \overline{\nu}$ $\frac{g_A}{g_V}$	1.2×10^3	1.2×10^4	10
$\Sigma^- \to \Lambda e^- \nu$ $\frac{g_A}{g_V}$	108	2200	20
$\Sigma^+ \to \Lambda e^+ \nu$ $\frac{g_A}{g_V}$	25	360	14

TABLE 5

Nimrod Experiments — Elastic Scattering

	Group	Proposal No.	Experiment	State	Measurements
πN	UCL	74	$\pi^+ p$ $\frac{d\sigma}{d\Omega}$	Analysis complete. Submitted for publication	14 momenta; 1.0 - 1.4 GeV/c and 1.715 GeV/c
πN	RHEL (C)	55	$\pi^+ p$ polarised target	Analysis	68 momenta; 0.6 - 2.70 GeV/c
πN	Bristol/Soton/RHEL	83	$\pi^+ p$ $\frac{d\sigma}{d\Omega}$	Running	30 momenta; 0.6 - 2.0 GeV/c
KN	B'ham/RHEL	40	$K^- p$ $\frac{d\sigma}{d\Omega}$	Analysis	14 momenta; 0.60 - 0.93 GeV/c
KN	"	63	$K^+ p$ $\frac{d\sigma}{d\Omega}$	Analysis	13 momenta; 0.43 - 0.93 GeV/c
KN	"	73	$K^{\pm} n$ $\frac{d\sigma}{d\Omega}$	Running	7 momenta; 0.43 - 0.94 GeV/c 14 momenta; 0.59 - 0.94 GeV/c
KN	UCL/RHEL	30	$K^- p$ $\frac{d\sigma}{d\Omega}$	Analysis complete. Submitted for publication	13 momenta; 1.0 - 1.4 GeV/c 19 momenta; 1.7 - 2.4 GeV/c
KN	"	74	$K^+ p$ $\frac{d\sigma}{d\Omega}$	Analysis complete. Submitted for publication	28 momenta; 1.4 - 2.3 GeV/c
KN	Bristol/Soton/RHEL	43	$K^+ p$ $\frac{d\sigma}{d\Omega}$	Analysis	17 momenta; 0.9 - 1.9 GeV/c

TABLE 6

Nimrod Experiments on Inelastic Reactions

	Group	Proposal No	Experiment	State	Measurements
πN	IC/Soton/RHEL	50	$\pi^- p \rightarrow p\, X^-$ resonance $n\, X^o$ search	Analysis	$\pi^- p$ 0.7 - 4 GeV/c $M(X^o)$ covered 500 - 2000 MeV/c^2
	IC/Soton/RHEL	99	$\pi^- p \rightarrow p\, X^-$ resonance $n\, X^o$ search	Setting-up	$p\pi^-$ 0.7 - 4 GeV/c Further studies of the η ω and A_2
	Camb/RHEL(B)	87	$\pi^- p \rightarrow \Lambda^o K^o$ $\frac{d\sigma}{d\Omega}$ p	Setting-up	17 momenta 10^4 events/momentum
	Glasgow/RHEL(C)	81	$\pi^- p \rightarrow \pi^o n$ p $\rightarrow \eta^o n$	Setting-up	0.6 - 3.5 GeV/c
	Glasgow/RHEL(C)	101	$\pi^- p \rightarrow \pi^o n$ $\frac{d\sigma}{d\Omega}$ $\rightarrow \eta^o n$	Setting-up	0.6 - 3.5 GeV/c
KN	Oxford	33	$K^- p \rightarrow$ neutral	Analysis	16 momenta 0.685 - 0.990 MeV/c $\sim$ 3,500 $\Lambda\pi^o$; $\sim$ 1,600 $\Sigma^o\pi^o$
	Oxford	92	$K^- p \rightarrow$ neutral	Data taking	7 momenta 0.9 - 1.1 GeV/c Expected yield $\sim$ 20,000 $\Lambda\pi^o$; $\sim$ 5,000 $\Sigma^o\pi^o$
	B'ham/RHEL	73	$K^+ n \rightarrow K^o p$ $\frac{d\sigma}{d\Omega}$	Running	13 momenta 0.45 - 0.95 GeV/c

TABLE 7

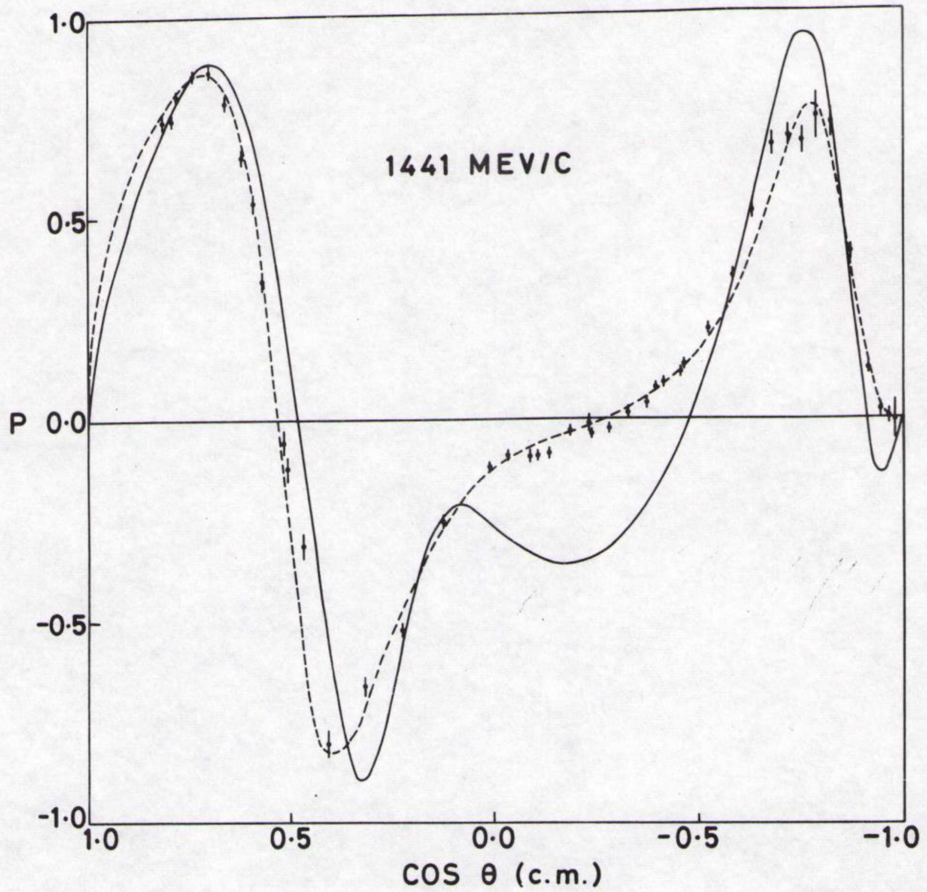
Nimrod Experiments on Weak and Electro-Magnetic Interaction

	Group	Proposal No	Experiment	State	Meas ements
Weak Interaction	Camb/RHEL	45	Test of $\Delta S = \Delta Q$ rule	About to be published	Test of $\Delta S = \Delta Q$ rule using $K \rightarrow \pi e \nu$ produced by $\pi^- p \rightarrow \Lambda^o K^o$
E-M Interaction	Westfield/RHEL	70	$\eta^o \rightarrow \pi^+ \pi^- \pi^o$ $\rightarrow \pi^+ \pi^- \gamma$	Analysis	Estimated 350,000 $\pi^+ \pi^- \pi^o$ decays obtained Measure of charge asymmetry
	Westfield/RHEL	76	$\eta^o \rightarrow e^+ e^- \pi^o$	Analysis	Search for C violating decay
	Camb/RHEL	78	Search for anomalies in Bremsstrahlung	About to be published	Search for new particles and for anomalies in Bremsstrahlung

TABLE 8

Time spent on Nimrod to particular fields of study

Subject	Number of group years devoted to subject	Percentage
$\pi N \rightarrow \pi N$	$7\frac{1}{2}$	24%
$KN \rightarrow KN$	5	16%
Other strong interactions	9	29%
Weak interactions	6	19%
Electro-magnetic interactions	$3\frac{1}{2}$	12%
TOTAL	31	100%


1441 MEV/C
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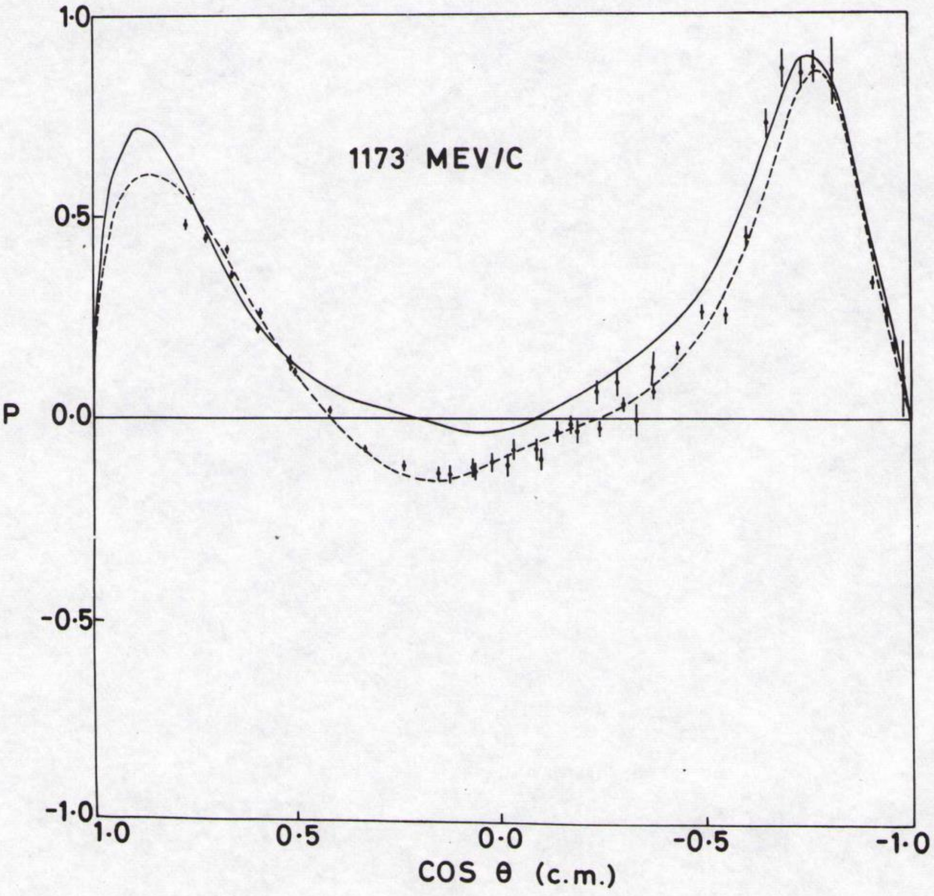
1173 MEV/C
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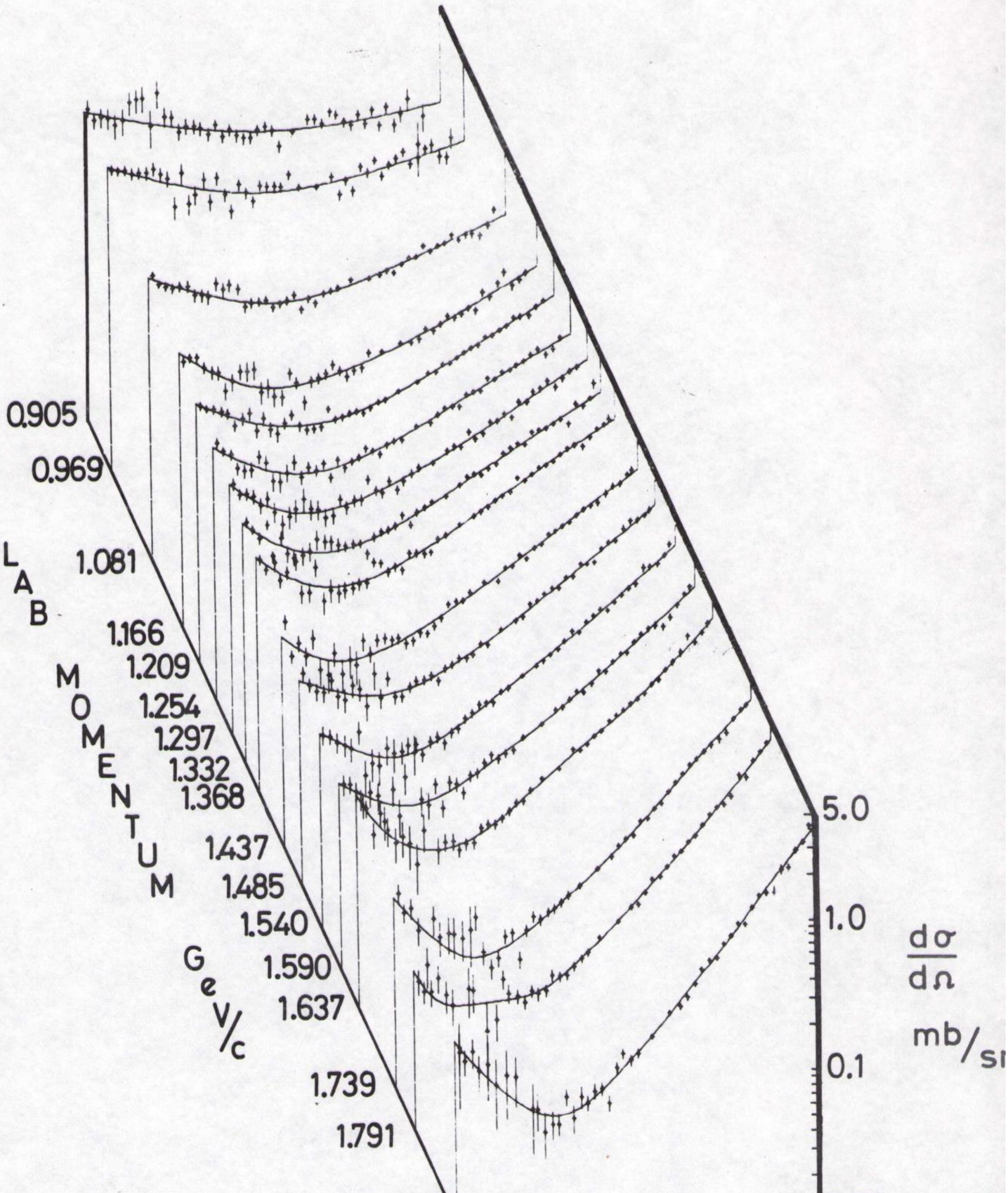


FIG 5 DIFFERENTIAL CROSS SECTIONS FOR K^+p ELASTIC SCATTERING

For completeness an example will be given of a very important experiment for which Nimrod is very well suited. This is the study by a Westfield College/ Rutherford Laboratory Group of the charge symmetry in $\eta^{o} \rightarrow \pi^{+}\pi^{-}\pi^{o}$ and $\eta \rightarrow \pi^{+}\pi^{-}\gamma$. A detector using 60 neutron counters in time-of-flight to select η from the reaction $\pi^{-} p \rightarrow \eta^{o} n$ was set up in which the η decay particles were detected in optical spark chambers situated in a large magnet viewed by a videcon system. An effective mass resolution for the η of ± 4.5 MeV was achieved. About 700,000 $\eta \rightarrow \pi^{+}\pi^{-}\pi^{o}$ decays have been recorded which should yield an accuracy on the asymmetry of $\sim \pm 0.2\%$. A second experiment by the same group is searching for the C violating decay $\eta^{o} \rightarrow \pi^{o}e^{+}e^{-}$ and should improve the present limit on the branching ratio of 2×10^{-4} by about a factor of 10.

4.4. Bubble Chamber Programme

Table 9 lists bubble chamber exposures taken at Nimrod that are still under analysis.

The only proposals remaining are in the 150 cm hydrogen chamber with a track sensitive hydrogen or deuterium target and a neon-hydrogen filling for the chamber (see Section 7.3 below).

Three proposals have been made for experiments using the target facility (see Table 10) and if the system is successful, it will provide a valuable complement to the CERN chambers. Proposals will be accepted from both British and other European groups.

Nimrod is the second highest energy proton synchrotron in Western Europe. Its programme of systematic studies in the resonance regions can complement the CERN programme very satisfactorily. All the experimental work described above could, of course, be done equally well at CERN if one chose to make sufficient machine time and experimental floor space available. It is, however, open to question whether this would be the best use of the higher energy machine taking into account all the demands that increasingly are being put upon it.

5. IMPROVEMENTS TO NIMROD

Nimrod is also capable of considerable development and if this were to be done the scope of the experimental programme described above would be considerably enhanced.

TABLE 9

Bubble Chamber Experiments at Nimrod, being analysed

Group	Proposal No.	Experiment	Measurements
CEN (Saclay)/College de France/Strasbourg/RHEL	18	K^-p interactions; 1.25 - 1.85 GeV/c	1.65×10^6 pictures; 13 momenta. Formation of S = -1 baryon resonances
B'ham/Edinburgh/Glasgow/Imp. Coll.	18	K^-d interactions; 1.45 and 1.65 GeV/c	0.72×10^6 pictures. Study of $K^-d \rightarrow \Lambda\pi^-p$ to select $K^-n \rightarrow \Lambda\pi^-$
Univ.Coll/Tufts Univ./Brussels/CERN	38	2.2 GeV/c K^- exposure in the 1.4m Heavy Liquid Bubble Chamber	0.68×10^6 pictures. Lifetime of Ξ^o. Study of Λ-Λ interaction and Ξ^-, Ξ^* resonances. Search for X^o, ϕ^o neutral decays and radiative Y^* decays
Imp.Coll./Westfield/Cambridge	39, 57, 86	π^+p interactions 0.8 - 1.7 GeV/c	0.42×10^6 pictures; 11 momenta. Formation of baryon resonances with S = 0, I = 3/2
Cambridge	Addendum to 49	n-p interactions; 1 - 7.5 GeV/c	0.11×10^6 pictures. Single and multiple pion production. Strange particle production
CEN (Saclay)/Imp. College/Westfield	56	K^+n interactions in the 2 to 3 GeV/c region	0.29×10^6 pictures K^+p 0.8×10^6 pictures k^+d Search for exotic baryon states, e.g. Z^*
Cambridge	77	1 GeV/c electrons into hydrogen bubble chamber	0.29×10^6 pictures. Anomalies in electromagnetic processes
Cambridge	85	n-p interactions from 1 - 3.5 GeV/c	0.09×10^6 pictures; improved n beam. High statistics study of $np \rightarrow pp\pi^-$ $\rightarrow pp\pi^-\pi^o$ $pn\pi^+\pi^-$
Univ.Coll./Durham/CERN/RHEL	91	π^+p interactions in neon-hydrogen track sensitive target	0.06×10^6 pictures for development and data taking

TABLE 10

Bubble Chamber Proposals to use Target Facility

Group	Proposal No.	Target Filling	Chamber Filling Neon/H_2	Exposure	Aims of Experiment
RHEL/Durham/CERN/ UCL	91	H_2	50/50	250,000 pictures 4 GeV/c π^+	Investigate A_2^+ splitting and H meson, and $\pi^o\pi^o$ from $\pi^+p \rightarrow \Delta^{++}\pi^o\pi^o$
Oxford	68	D_2	95/5	500,000 pictures 2 GeV/c π^+	$\pi^+d \rightarrow pp\pi^o\pi^o$ investigate $\pi^o\pi^o$ interaction
UCL	84	H_2	90/10 if possible	500,000 pictures p_K 0.4 - 0.8 GeV/c	$K^-p \rightarrow \Sigma^o\pi^o$ and other final states involving γ's

5.1. Machine Development

Only one improvement is at present being done to Nimrod, namely the construction of an additional rf cavity working at the second harmonic of the main frequency. This will improve the present circulating intensity by a factor of 1.4 and enable us to obtain the extracted proton beams of 2×10^{12} protons per pulse quoted above.

Plans are, however, being considered to replace the present 15 MeV injector by a 70 MeV linear accelerator. It is calculated that this would raise the external proton beam intensity available from Nimrod to 10^{13} protons per pulse.

5.2. Beam Improvements

A design has been made for a stopped kaon beam and the relevant parameters are given in Table 11. The yield for K^+ in flight is in the region $4 - 7 \times 10^4$ depending upon settings of the mass and momentum slits. The yield for K^- is down by a factor of ~ 4. Separation could be improved at the cost of a reduced yield.

Another growing requirement is for higher momentum pion beams and hence some of the beams will be redesigned to go to higher momentum including one capable of reaching 7 GeV/c.

A third interest is an improved K beam for counter experiments, particularly with some separation to improve the K/π rates, hence a development programme is under way on superconducting rf separators using lead cavities.

6. COMPUTING AND DATA ANALYSIS

Our IBM 360/75 computer was replaced by an IBM 360/195 at the end of 1971. It will be updated to a model 370/195 in 1973. As with all the Laboratory's facilities, the computer is for use by University groups affiliated to the Laboratory. We are now also going ahead installing Work Stations in University departments. Each Work Station will have a card reader, a line printer and a mini-computer. This will enable the Universities to have direct access to the powerful computing facilities at the Rutherford Laboratory from within their own departments.

The Laboratory has three automatic film measuring machines in operation. The two main ones are of the flying spot digitizer type - HPD I and HPD II. HPD II is an improvement on HPD I. It is faster and uses a laser generated light spot. In 1971 HPD I measured 330,000 events from the CERN 2m bubble chamber. The projected capacity for 1972 is 500,000 and the full use of HPD II would bring Laboratory measuring potential up to 1.0 to 1.5×10^6 events - if enough rough digitizing capacity was available or if an effective minimum guidance system was developed.

TABLE 11

STOPPING K^+ BEAM - ESTIMATED PROPERTIES AT FINAL FOCUS

Production Angle = 5°

Target = 4mm x 4mm x 100mm copper

	Momentum Slit (Half-Width) mm	Mass Slit (Half-Width) mm	Integrated acceptance for K^+ (m st.%$\Delta p/p$)	K^+ flux at final focus (600 MeV/c 10^{12} protons)	% Momentum bite (FWHH)	π^+/K^+ at focus
BBB/22	50	10	28.4	3.2×10^4	2.5	20:1
	75	15	37.3	4.0×10^4	3.4	30:1
	100	20	40.4	4.4×10^4	3.5	50:1
BBB/BB	50	10	40.9	4.4×10^4	3.1	25:1
	75	15	57.4	6.4×10^4	4.0	35:1
	100	20	64.2	7.2×10^4	4.2	60:1

BBB/22 ≡ 3 Berkeley Type Quadrupoles + 2 RHEL Type 2 Quadrupoles

BBB/BB ≡ 5 Berkeley Type Quadrupoles

7. THE APPLIED PHYSICS SUPPORT PROGRAMME

7.1. General

Experiments in high energy physics increasingly require the use of sophisticated apparatus incorporating a wide range of the products of modern technology. In considering the future demands of the subject it is therefore not surprising to find that further technological developments are constantly being anticipated in the forward planning of many of the new experiments and facilities of high energy physics.

In the broadest terms these anticipated developments can be divided into two categories. Those in the first category are to be found in branches of technology that hold sufficient common interest for both nuclear physics and other subjects for their joint needs to be recognised and acted upon by specialist organisations, usually industrial. No direct involvement or support from the nuclear physicist is called for in the research programme leading to the anticipated developments; he can rest assured that his future requirements have not escaped the attention they deserve. An example of technology in this category is the development of the digital computer where progress in keeping with the demands of high energy physics continues to be made without direct intervention.

The second category covers those branches of technology which are uniquely associated with nuclear physics apparatus or in which the anticipated developments are not mirrored in other branches of science to any comparable extent. Examples include superconducting magnet development, bubble chambers, spark chambers and polarised targets. Without direct support at the appropriate level from nuclear physics resources, progress on items under this heading would diminish, and in some cases cease altogether. Much of the apparatus of high energy physics would then quickly become stagnant in concept. It is to avoid such a situation arising that groups specialising in applied physics are to be found in the accelerator laboratories of the world engaged in development programmes aimed at significant improvements in nuclear physics instrumentation. The Rutherford Laboratory has a strong applied physics support programme, the main parts of which are described below.

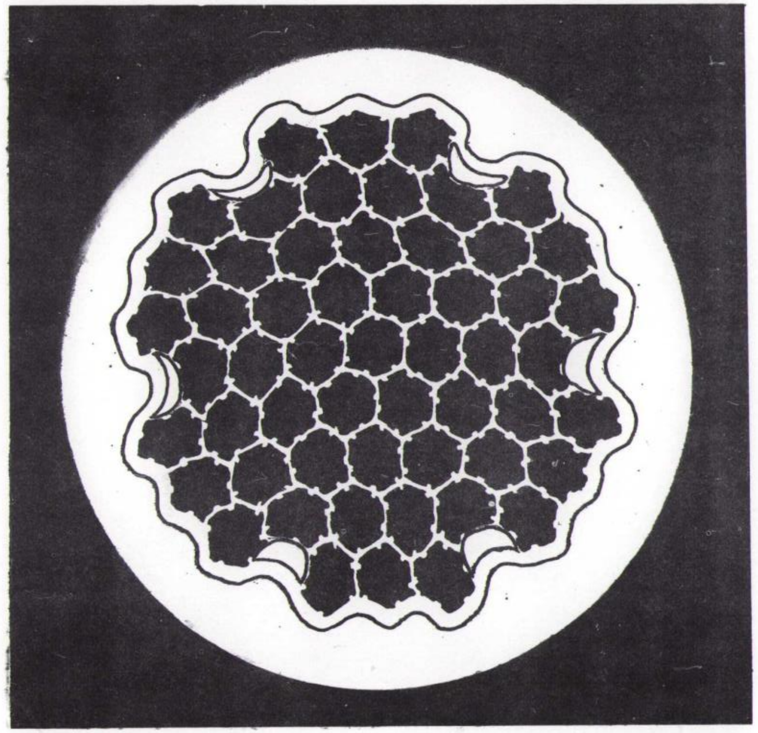
7.2. The Superconducting Magnet Programme

The design of much of the large scale equipment used in high energy physics is restricted by the capabilities of conventional iron-cored magnets. The discovery in 1961 of low temperature superconducting materials which would sustain very high currents in high magnetic fields (up to 100 kG or more) with negligible power dissipation made it possible to envisage more powerful devices which would be either technically impossible or prohibitively expensive using conventional techniques. Specific potential applications of superconducting magnets include large volumes of magnetic field for bubble chambers and spark chambers, higher strength particle bending and focusing magnets, and higher energy particle accelerators and storage rings. Synchrotron power supplies based on inductive energy storage also become feasible.

The Rutherford Laboratory has taken a special interest in the development and application of this new technology and has been responsible for initiating a number of significant developments. In particular the concept of intrinsically stable multi-filament superconducting composities now being extensively utilised throughout the world is usually attributed to P F Smith and his collaborators working in the Rutherford Laboratory. A comprehensive development programme aimed primarily at establishing the technical feasibility of superconducting particle accelerators is at present in progress. The work is now aimed specifically at the needs of the CERN II programme for increasing the machine energy. Suitable conductors are now commercially available. Figure 6 shows such a conductor. It contains 3025 fine filaments sheathed in a resistive cupro-nickel matrix.

With the conductor problems relatively well understood, the engineering problems are now being faced of achieving (at reasonable cost) the stringent synchrotron specifications of typically 1 part in 10^3 field uniformity for the dipole magnets, and typically 10^8 pulse lifetime. This has necessitated a concerted effort during the past two years in order to attack the range of novel electrical, cryogenic, structural and materials problems which arise; much progress has been made, and the first prototype pulsed magnet of realistic size and design parameters has operated successfully. Further prototypes are in the design stage.

Another novel feature of the superconducting applications programme at the Laboratory has been the evolution of a new concept in synchrotron power supplies. The latter may represent a significant design problem in the case of the largest accelerators, which require an electrical energy in the region 10^8 - 10^9 Joules to be supplied to and extracted from the magnets every few seconds. In the case of superconducting magnets, it was recognised that an attractive alternative could be to store the energy in several large superconducting coils, provided that an efficient means of transferring the energy could be devised. A scheme



(mag x 250)

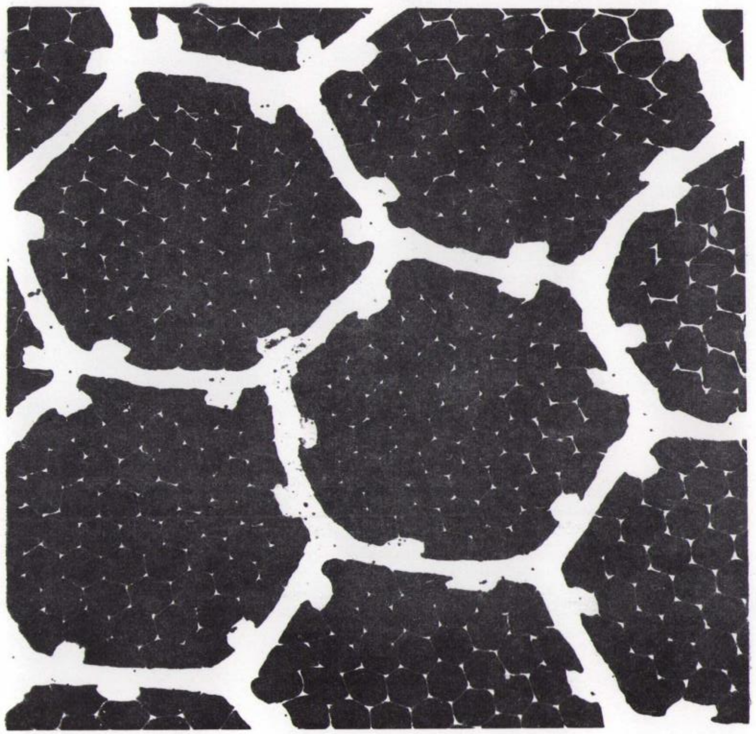


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Figure 6 Cross section of a filamentary superconductor intended for pulsed application. The 3025 filaments of niobium titanium, each 4 microns in diameter, are separated by a resistive cupro-nickel matrix to reduce eddy currents between filaments. A copper sheath around the whole composite provides protection and some additional stability. Conductor overall diameter 0.4 mm.

has recently been evolved which achieves this simply by varying the mutual coupling between three concentric superconducting coils (by slow relative rotation), resulting in redistribution of flux at constant total energy and does not require any additional external work. The system is thus self-contained and reversible, and may constitute a simpler and possibly cheaper method of powering a synchrotron magnet.

A number of refinements and extensions of this idea have been devised, and a study of some of the design and engineering problems is in progress.

7.3. Track Sensitive Bubble Chamber Targets

In early 1965 the Brookhaven National Laboratory bubble chamber group successfully operated their 20 inch chamber filled with a mixture of neon and hydrogen liquids. In 1965 Streett and Jones investigated the phase equilibrium of neon/hydrogen binary mixtures throughout a wide range of temperatures and compositions. They showed that there was a wide choice of temperatures and pressures where a stable monophase mixture of hydrogen and neon could exist. The conversion lengths of such mixtures was shown to be in the range normally covered by heavy liquid bubble chambers.

In 1967 Florent et al showed that it was possible to choose bubble chamber operating conditions in neon/hydrogen mixtures that were compatible with those used in hydrogen at the same temperature and pressure. This group successfully operated a liquid hydrogen filled mylar target inside the simultaneously sensitive 82 cm Bubble Chamber at DESY which contained a neon/hydrogen mixture with a neon concentration of 15 molecular %. In future experiments carried out at DESY the target was filled with deuterium and the surrounding fluid was neon/hydrogen mixture with 95 molecular % neon present.

At this time it was decided that a collaboration between CERN and the Rutherford Laboratory would be set up to lead to the establishment of a target facility in the 1.5 m cryogenic bubble chamber. A series of targets in the form of flat sided perspex containers were designed at CERN and the engineering modifications to the bubble chamber systems required to handle the mixed fillings and to operate the target were undertaken by the Rutherford Laboratory. The first target was installed and operated in May 1969. The neon concentration in the neon-hydrogen mixture surrounding the target was 40 molecular %. Approximately 200,000 expansions were performed and 40,000 pictures taken with good track quality both inside and outside the target before the target failed mechanically as a result of the fracture of the perspex mounting pin by which it was retained in the chamber. The results obtained with this first target were very encouraging and a new target was made in which the fixing to the chamber was much improved. This was installed in July 1969 and with the chamber containing 50 molecular % neon, further tests were commenced. After about 3,000 expansions the target failed due to uncontrolled internal boiling giving rise to an increase in volume which fractured the brittle container. After this two more targets were to fail before the true cause of the failure led to the design of a target very different from the original concept which has now operated successfully.

7.4. Fast Cycling Vertex Detectors

The use of a fast cycling bubble chamber in combination with a counter array has been considered by a number of laboratories. An early example of such a system was used at the Princeton-Pennsylvania Accelerator and comprised a liquid hydrogen bubble chamber of 30ℓ volume operating at up to 19 Hz surrounded by an array of 96 scintillation counters. This work was done in 1965 and since then a number of groups have attempted to operate fast cycling bubble chambers. The group at SLAC has been particularly successful in this field having produced two small chambers, one 15 cm diameter by 5 cm deep, and another 10 cm diameter by 7 cm deep, which has operated at 90 Hz. They are now working on a larger chamber some 38 cm diameter by 14 cm deep to operate at 60 Hz.

In the Rutherford Laboratory a design study for a fast cycling chamber has been completed and experiments proposed for its use on Nimrod. The specification of the chamber system is as follows:-

Chamber diameter	30 cm
Chamber depth	15 cm
Solid angle availability	$\sim 3\pi$
Operating frequency	60 Hz
Operating fluid	Hydrogen or deuterium
Optical system	Bright field retrodirective using three cameras
Optical resolution	100 microns
Stereo angle	8°

Details are shown in figures 7 and 8.

7.5. Polarized Targets

The Laboratory has an active group engaged in the development and construction of polarized targets. On our latest target effort has been concentrated on obtaining a large solid angle. The requirement for large access to the target

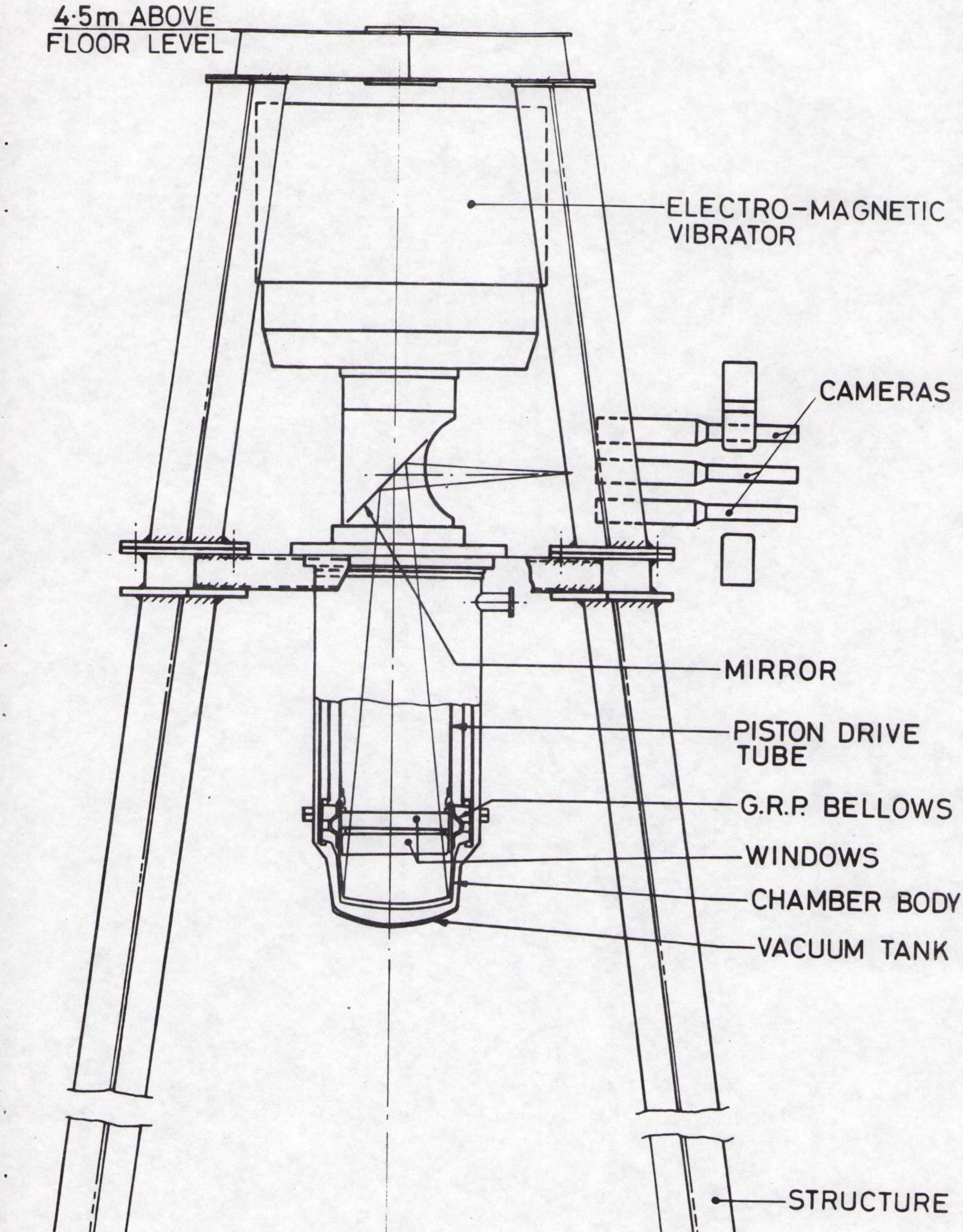

FIGURE 7 PROPOSED RAPID CYCLING VERTEX DETECTOR

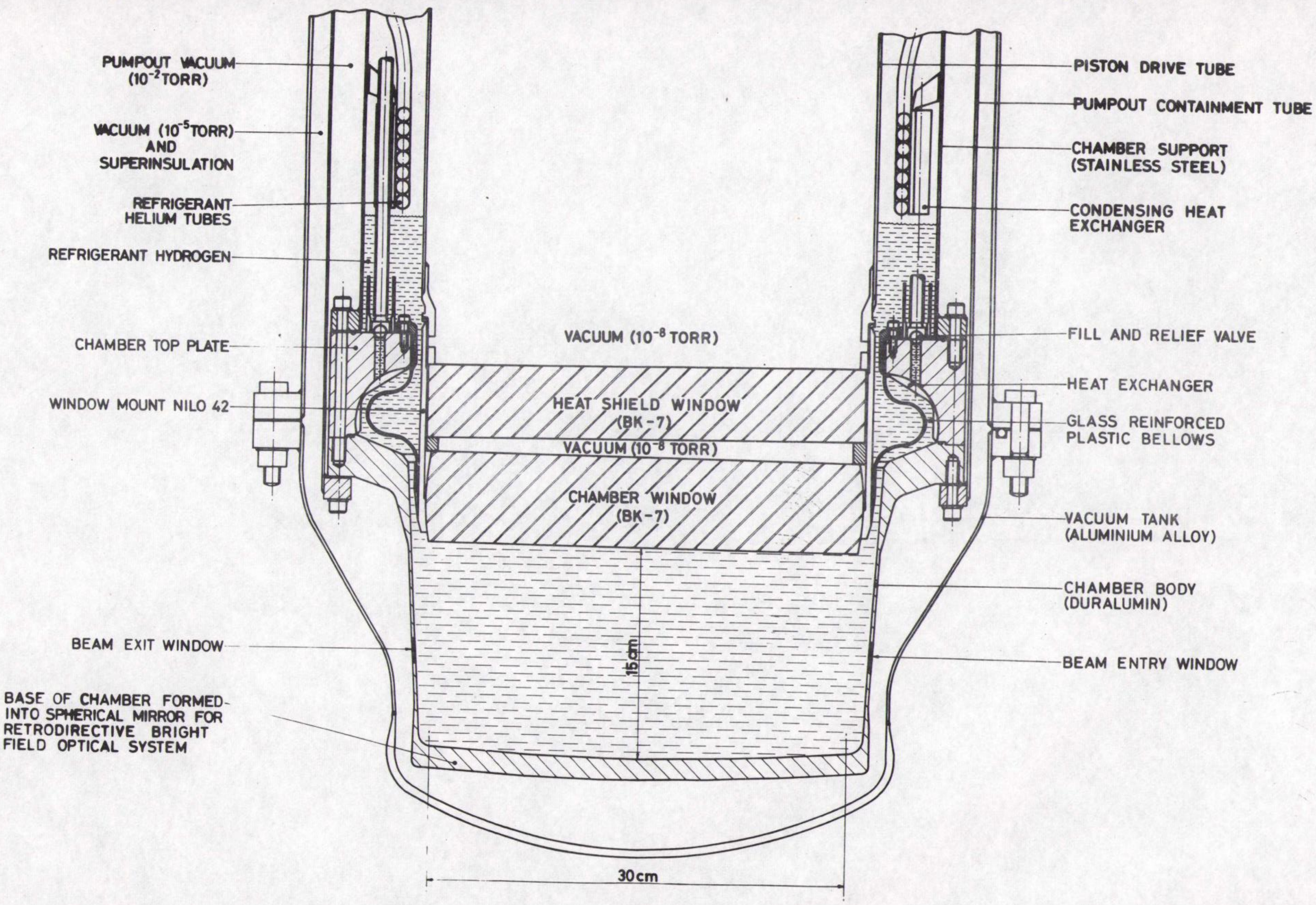

FIGURE 8 **DETAILS OF RAPID CYCLING VERTEX DETECTOR**

prevents the magnetic field at the target from being sufficiently uniform for the target to be polarised in situ. Consequently it is necessary for the target to be moved to a region of uniform magnetic field where it is polarised After polarisation has been established in this uniform field region, the temperature of the target material is reduced to such an extent that the process of spin relaxation from thermal agitation in the lattice is negligible. In effect the proton polarisation is frozen into the sample. In this state the target material can be transferred to the holding magnetic field where the angle of access is large. During the time the target is in use in the holding field region the polarisation slowly decays, so that the target must be periodically returned to the uniform field region for repolarisation. To achieve sufficiently long proton spin relaxation times the temperature of the target much be reduced to below $0.3^{\circ}K$ for periods of several hours. This has necessitated the development of a closed cycle helium-3 refrigerator system capable of handling the higher powers associated with polarisation as well as the low temperature conditions associated with the frozen spin state.

The magnets for this new target pose a serious design problem in that the decay of polarisation in the holding position is strongly dependent upon the strength of the magnetic field at that point, demanding a high peak field. New and advanced techniques have been employed to construct a magnet capable of giving about 30 kG at its centre with a 90° angle of access. This superconducting holding magnet is shown in Figure 9 and a schematic diagram of the Frozen Target system is shown in Figure 10.

For successful operation of a target of this type it is necessary for high polarisations to be achieved simultaneously with long relaxation time. Unfortunately these two parameters are closely related and the newer organic materials proved unsatisfactory. A program was initiated to develop a suitable material for this target. This work led to a successful development of a material in the form of a glycerol-water mixture using the free-radical porphyrexide to provide for free electrons for polarisation purposes.

During the development of this target there has been considerable theoretical work investigating the various possibilities that have occurred for better future targets. One area that is to be explored in the near future is the behaviour of the new organic materials and selected inorganic materials, such as the potentially very attractive material ammonia, at temperatures less than $0.1^{\circ}K$. For this purpose a dilution refrigerator will be used. In addition to continuation of this materials work investigations are currently in progress on the use of new target techniques. For example, the use of two polarised targets

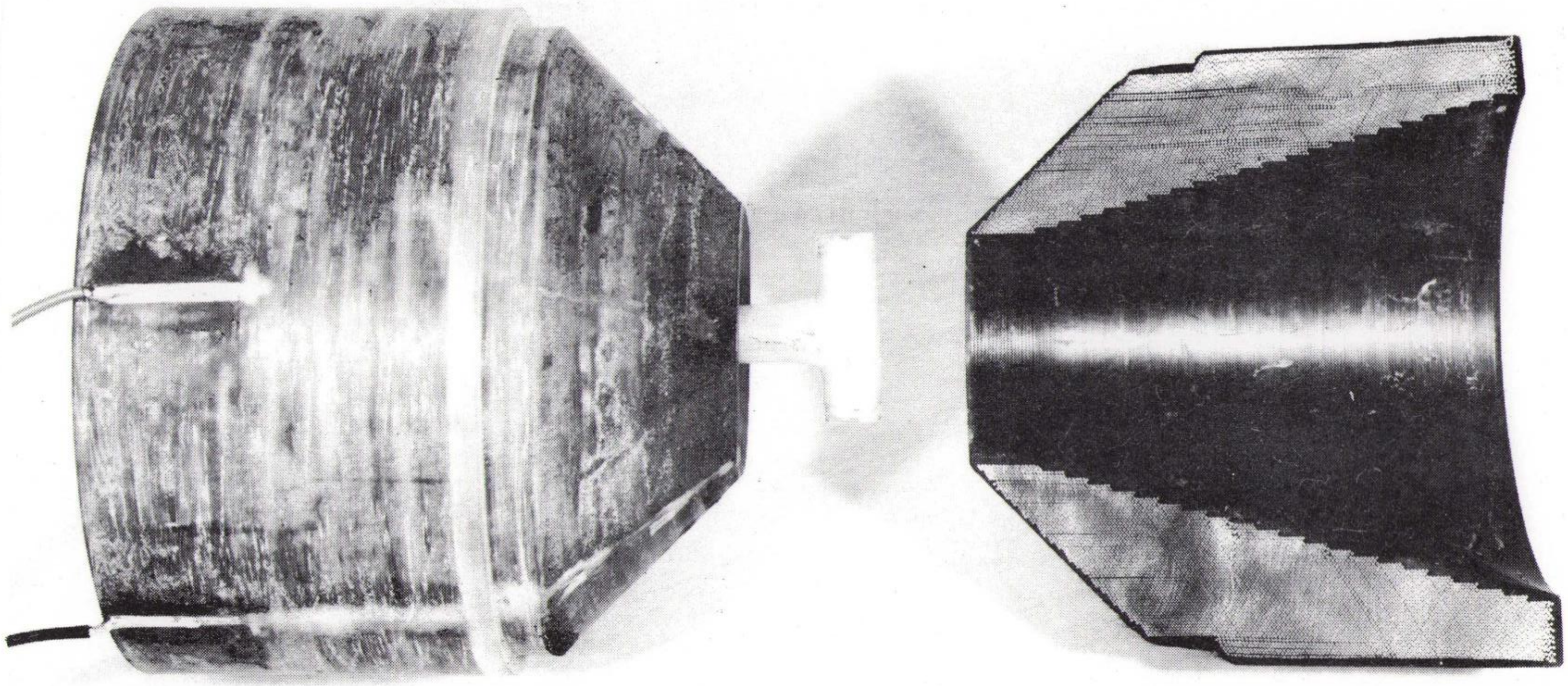

Figure 9 Superconducting holding magnet for polarised target. In the photograph one of the pairs of coils has been replaced by a dummy copper coil which has been sectioned to illustrate the construction technique used. The coil is wound from 1 mm diameter 361 filament twisted conductor and is vacuum impregnated with epoxy resin. The coil produces a central field of 30 kG operating at a temperature 2.5K with a peak field on the conductor of almost 80 kG.

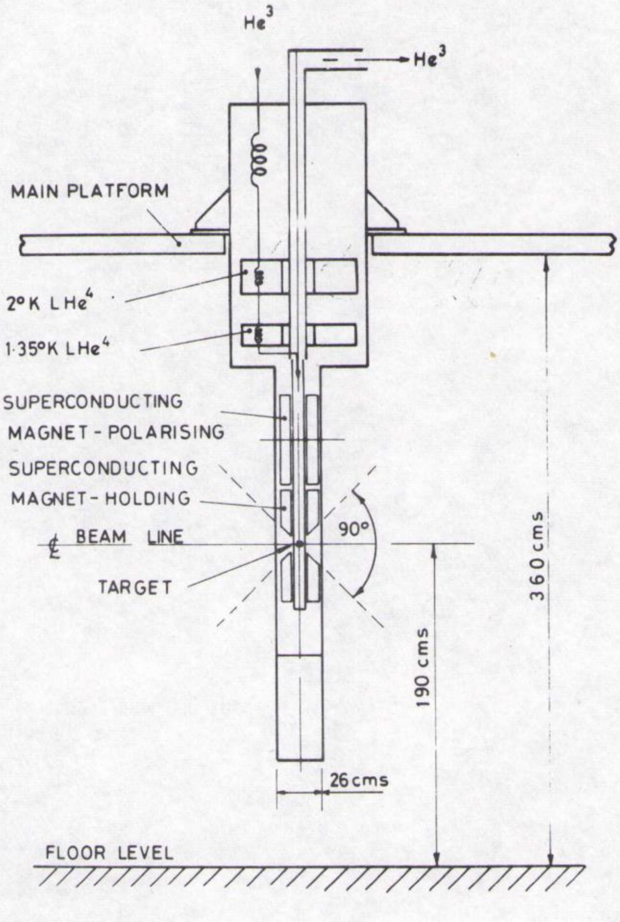

Figure 10 Schematic diagram of Frozen Polarised Target

within one cryogenic enclosure with the separate targets polarised permanently in opposite directions is being studied. Such an arrangement overcomes all of the disadvantages of the Frozen Target arrangement. In particular, it avoids having to compromise on degree of polarisation to achieve an acceptably long relaxation time. Materials selected for high polarisation and high free-to-bound ratio of protons can as a result be used. Work also is in progress exploring the use of materials for field shaping purposes. Study work is proceeding on the design of a special magnet to replace the large access holding magnet in the Frozen Target to permit measurement of Wolfenstein A and R polarisation parameters.

Looking further into the future the feasibility of constructing a large volume polarised target has been explored for use with the high energy beams soon to become available from the new large accelerators at NAL and CERN. From this study it is concluded that a target with active volume of about 3ℓ could be constructed using existing techniques and materials by exploiting the properties of a twin Frozen Target.

7.6. Superconducting RF Separators

It is well known that at high momenta RF separators give a greater yield of wanted particles than the electrostatic type. Even at the momenta of Nimrod secondary beams, significant increases in yield are obtainable. RF separators operating at room temperature have been in use for many years for bubble chamber beams; however, for counter application requiring long RF pulse lengths and high duty cycle (eg 50 ms pulses, 15% duty cycle), the RF separator must be superconducting.

A feasibility study of superconducting RF separators has been undertaken at the Rutherford Laboratory. The study is based on lead as the superconductor electro-deposited on to a copper substrate surface on the grounds of relatively easy technology and cost. The proposed RF separators have been designed with a geometry and field levels to match the capabilities of lead - in particular the maximum mean deflecting field E_o = 3.6 MV/m, for which the magnetic and electric fields at the surface are 540 gauss and 13.8 MV/m. At the design operating temperature of 1.85^{o}K, the critical magnetic field for lead is 750 gauss.

A test programme has been undertaken to prove that lead on its copper substrate can sustain such large magnetic fields. A 2-cell model of an RF separator cavity at the full scale frquency of 1.3 GHz has been built. The model cavity substrate is made in one piece from electroformed copper (to avoid the problem of RF joints) and contains end-sections with short lengths of beam pipe to simulate a realistic section of deflecting structure. Elaborate precautions are taken to clean the cavity prior to lead plating, and the anodes themselves are specially shaped and made from lead 99.9999% pure. After manufacture, great care is taken to dry the lead free of stains. The assembled structure is baked-out at 100-110^{o}C for some 48 hours, prior to cooling down slowly, first with liquid nitrogen and then with liquid helium to 4.2^{o}K. At 4.2^{o}K the low power intrinsic Q-value was found to be 1.64×10^{8}, ie 84% of the theoretical value. On pump-down to 2.05^{o}K (a value limited by vacuum difficulties), the Q value at low power improved to 5.6×10^{8}, falling to 1.8×10^{8} on the application of high power. The highest magnetic field achieved was 410 gauss and electric field 10 MV/m. (The corresponding mean deflecting field for a full size structure would be Eo = 2.74 MV/m.) These results are sufficiently encouraging to warrant proceeding with a full scale 10-cell separator cavity.

7.7. A Plumbicon camera system for the Omega project

A good example of collaboration between the Rutherford Laboratory and CERN is in the development of the Plumbicon camera system for use with the Omega project. A proposal that such a camera system should be built was made in January 1971 by a team from Birmingham University, Westfield College, London, and the Rutherford Laboratory. This proposal was accepted, and work is now proceeding on prototype cameras at the Rutherford Laboratory. The collaborative efforts of these groups will thus provide for the general use on experiments in the Omega spark chamber array an advanced automatic read-out system. This system of television cameras was suggested as an alternative to the film cameras originally proposed to avoid the time consuming business of scanning and measuring photographs. It gives automatic rapid read-out of spark chamber co-ordinates. It was selected in preference to solutions involving magneto-strictive and core read-out wire chambers which are difficult to operate in high magnetic fields, or sonic chambers which have poor multi-track capability or proportional chambers which, whilst being free of all the above problems, are not sufficiently developed for immediate use in Omega. A diagram taken from the original proposal document and showing the arrangement of the eight Plumbicon cameras with respect to the optical spark chambers in the Omega magnet is shown in Figure 11. The expected performance is as follows:

Accuracy	± 0.5 mm in space
Two spark resolution	10 mm in space
Sensitivity	∿90% efficient on five or six tracks in an Omega module at f 5.6
Dynamic Range Capability for Spark Intensity	∿ 400 : 1
Data taking rate	up to 50 events per PS cycle

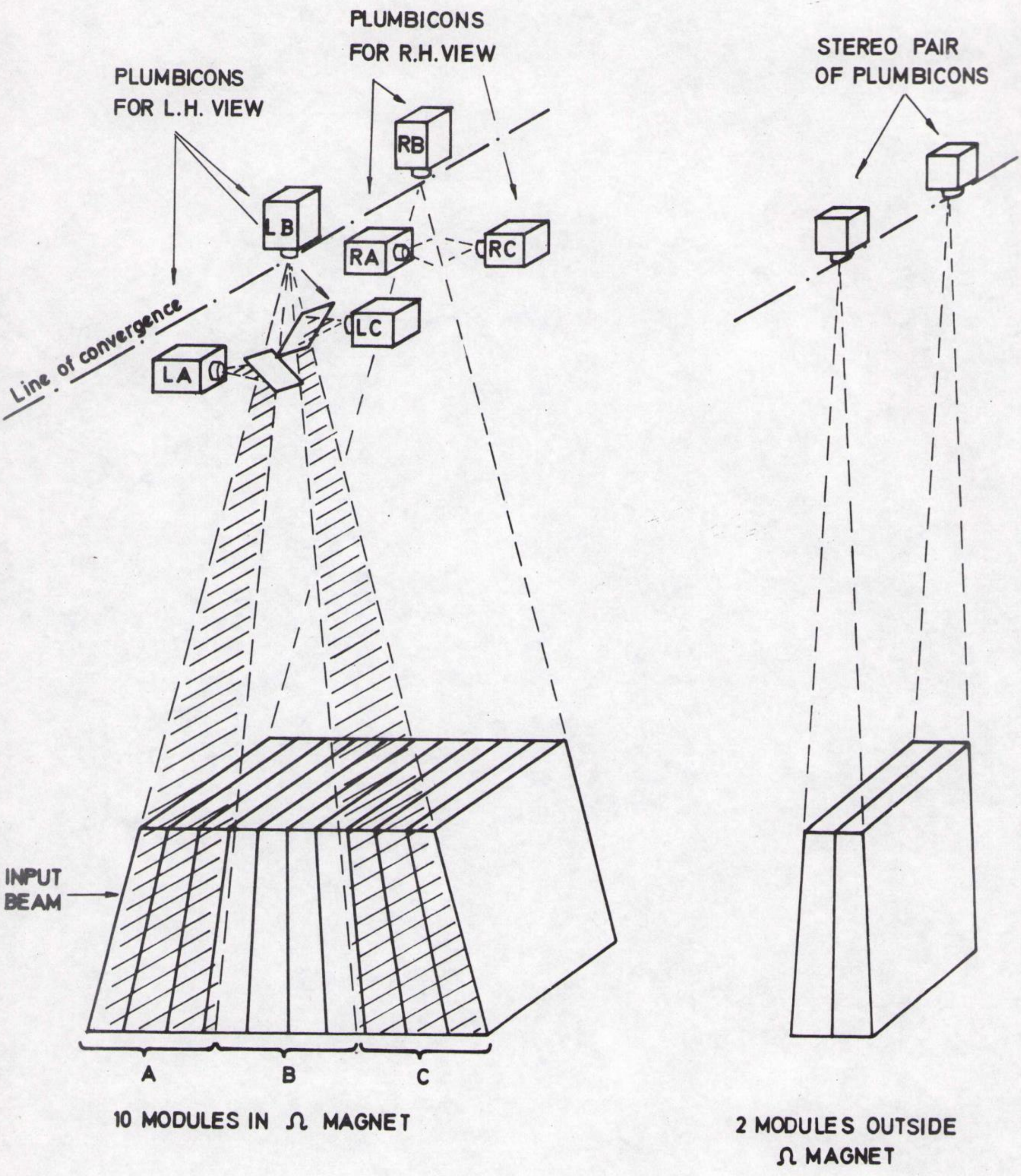

Figure 11 Optical arrangement for Plumbicon Cameras in Omega Spark Chamber Magnets.

8. CONCLUDING REMARKS

In the sections above I have given a brief factual account of the programme of the Rutherford Laboratory. Nimrod with its high beam intensity, flexibility in operation and potential for further improvement, has an important experimental role to play for at least the next decade complementing the work that will be done at higher energies on the CPS. I believe deeply in the importance of using Europe's accelerator resources for the common scientific good of the community and welcome proposals for experiments from physicists in all CERN Member States. If this eases the load on the CERN accelerators, well and good.

I believe too that with the inevitable drive towards higher and higher energies and consequent increase in the sophistication and cost of experiments an increasingly greater fraction of the Rutherford Laboratory's programme will be linked with CERN. If handled in the right way, collaboration could be very a exciting development. I believe also that if there is not an agreed policy of collaboration between the national laboratories and CERN, the long term effect would be generally harmful. In the United Kingdom our high energy physics policy is based on the belief that the life-blood of our subject is in the universities and that the national laboratories are there to support the University research by providing those resources which could not be made available economically or efficiently in individual departments. In the future I believe it will be equally important to preserve a proper balance between what work is done at the national centres and what is done internationally. ECFA could have a vital part to play in this area.