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EXPERIMENTAL BEAM TRANSPORT FACILITIES AT NINA

by

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Introduction

In this report, an assessment is given of the possible experimental magnet facilities, which will be required at Daresbury when NINA becomes operational in 1966. These magnets for initial experiments will be purchased if possible from the manufacturer as numberous designs are already available. The broad features and detection problems of the experiments are discussed to provide an indication of the experimental magnet facility required, in view of the large capital cost.

When NINA comes into operation, two existing accelerators of comparable energy (C.E.A. and D.E.S.Y.) will have been operative for some time (4 years and 2 years respectively). If NINA is to do good physics and compete favourably with these other laboratories then full use must be made of their initial studies, and experiments planned to take advantage of NINA's higher beam currents.

At an electron machine, the background flux of particles during the beam pulse is made up of two components, a direct target rate produced mainly by electrons (positrons) and converted γ-rays from the target and a room background rate produced almost entirely of neutrons (direct and scattered). The latter predominates at backward angles and is directly proportional to the counter volume, i.e. number of protons. This background can be minimised by the insertion of a focussing lens system, which reduces the counter volume for a given solid angle. The direct target contribution, consisting mainly of low energy electrons can be swept out by a magnetic field (fringing field); e.g. a 10Kgauss field inserted between target and counter reduces the instantaneous target rate by factors of 10^3 to 10^4. An estimate of the room background based on some figures from Cornell, including an improvement of a factor of ten in shielding, would give an instantaneous room background rate of 10^6/sec for a 6 in x 6 in x .25 in scintillation counter at 10 μamps beam current. These rates, admittedly high, can be handled with fast electronics, and provided the direct target background can be reduced by magnetic analysis, then it should be possible to realise the full potential of NINA. It is not easy to compare spark-chamber backgrounds with counters, since the spark-chamber is generally insensitive to neutrons. There is some evidence that the background is due to low energy γ-rays, but more information on this should be forthcoming.

High energy counter experiments can be executed in general by two methods. One approach is to design the experiment to give a high degree of discrimination with small energy and angular intervals, relying heavily on detailed knowledge of the machine energy, counter efficiencies, stability etc., and to measure the cross-section as a number on scaler or multichannel analyser. The second approach is to cover a wide angle and energy interval, collecting a large amount of information, labelling each event, and then selecting the relevant data. Both methods have their advantages depending on the type of experiment. The second method produces large time lags between data collection and publishable results, but this has been greatly reduced by on-line computing facilities provided the kinematical analysis is performed before the experimental run. The question of spark chamber versus counter hodoscope will not be discussed here as it is too complex and depends on the quantity measured. For many investigations, (e.g. bound pion states, ρ^os etc.) the spark-chamber is essential for particle mass determinations, for others (e.g. single pion production detection) it is a refinement. The high demand for machine time coupled to the data accumulation per incident particle and the long time interval (for development) between experiments has tended to emphasize the second approach. This should also be the approach at NINA, where on-line computing facilities will exist. An integral part of most experiments requiring good energy, i.e. momentum resolution, will be the uniform field bending magnet with the emphasis on wide air gaps for large acceptance and spark chamber insertion.

Magnets

1. Uniform Field Bending Magnets

Magnets (a) and (b) in fig. I serve similar purposes, both giving deflections in the horizontal plane. Magnet (b) requires more power for the same field strength and gap volume, but has a better field uniformity over the effective magnetic length. The C-type magnet is usually operated at small angles to the incident beam direction. It has very limited application since the large leakage flux sweeps all the low energy electrons/positrons into the gap region. A window frame magnet with removable iron slugs for beam access is preferred for small angle work.

The vertical deflection magnet (a, b rotated through 90^o) is suggested as a useful spectrometer at an electron accelerator in that it enables the experimentalist to work out of the horizontal plane of the beam. The window frame magnet with vacuum impregnated coils lends itself easily to this application without modification. For example, in inelastic electron studies, angular distributions in the vertical plane avoid particle detection close to the incident beam direction and similarly for the detection of wide angle decay secondaries ($\Lambda^o \rightarrow \pi^- + p, K^o \rightarrow \pi^+ + \pi^-$) in strange particle physics. Polarisation measurements above and below the production plane (assumed horizontal) are facilitated by a vertical deflection magnet.

The angular deflection of a singly charged particle is plotted as a function of the magnetic field and particle momentum for different magnet lengths in fig. II.

2. Quadrupole Magnets

The design of quadrupole magnets has almost become a cultural pursuit and hence many different types of quadrupoles are available in accelerator laboratories (fig. I). The conventional quadrupole (e) has circular aperture and comparatively low power consumption - a definite advantage in secondary beam design requiring sets of doublets and triplets. The single quadrupole produces no momentum dispersion to first order, but has been used effectively with a central stop in electron scattering (point source) experiments. The maximum dimension in the horizontal plane restricting the aperture at forward angles and the large unused fraction of the field region in counter experiments are its main drawbacks.

The Panofsky current sheet quadrupole (f) overcomes the above mentioned disadvantages and has been successfully used as a single particle analyser of large rectangular aperture (e.g. 20 in x 5 in) giving good momentum resolution for extended targets at momenta up to 2 BeV/c. The power consumption is much higher than that of the conventional quadrupole (by ~ a factor of 10 for the same length and gradient), as the quadrupole field is produced by the current sheet and the coil space is limited. The Lozenge quadrupole (g) halves the current sheet power requirements for the same aperture and gradient by chopping off the corners along an equipotential line, retaining the quadrupole field. The elliptical quadrupole also reduces the power requirements by defining an equipotential surface, reducing the rectangular aperture to an elliptical one with small aperture reduction.

The DESY type (h) is a hyperbolic pole face quadrupole, where the coil shape corrects the quadrupole field for increased aperture. For a given coil design, this magnet consumes one quarter of the power of the Panofsky rectangular current sheet magnet for the same field gradient, and provides a large inscribed rectangle in both horizontal and vertical dimensions. Although the power consumption of the DESY quadrupole is approximately three times that of a conventional one, the very linear quadrupole field distribution over the entire magnet combined with the large rectangular aperture in both dimensions gives the DESY quadrupole preference over the other types as a standard research facility for accurate measurements. The advantage of the rectangular quadrupole at small angles can be offset by the half quadrupole. In electron studies, the scattered electron yield α $1/\sin^4 \theta/2$, where θ is the angle between the incident and scattered electron directions and in two body photoproduction, the mesonic yield α $p\beta^2$ (p = meson momentum, β = meson velocity - all in the laboratory frame). In both processes, the yield increases rapidly in the forward direction and therefore the slight reduction in aperture of the half quadrupole is not serious. In fig.II, some quadrupole parameters are plotted as a function of the focussed particle momentum, for use in assessing beam handling facilities. It can be seen from the graph that for momenta above 2.2 BeV/c, the counter target distances become very long for a 40 inch long large bore quadrupole resulting in small apertures and increased non-analysed backgrounds. The single quadrupole has the merit of one dimensional focussing and bending in a single operation; e.g. the detection of short lived particles. Unfortunately the divergence of the rays in the defocussing plane require large counter dimensions in that plane, and make angular Cerenkov selection difficult at the higher momentum.

3. Two-three Quadrupole Systems

Two quadrupoles in the F/D mode form a convenient spectrometer in many experiments, since it is the simplest quadrupole system which provides a net focussing action in both dimensions. Unfortunately it is extremely astigmatic in that the magnifications in the horizontal and vertical planes are unequal. The inclusion of a bending magnet immediately after the doublet substantially reduces this effect. A common use of the quadrupole pair at momenta above 2 BeV/c is in the formation of a parallel beam between production target and detector for high selectivety of events (e.g. separating π's and k's using directional Cerenkov counter). This is then followed by a bending magnet to select the necessary momentum interval.

The combination of three quadrupoles forming a triplet also provides double focussing (not momentum). It has the advantage that the magnification in both dimensions can be made equal, and the focal length is less sensitive to momentum change than the doublet. Its application is mainly confined to the production of monchromatic beams (e.g. injection, secondary beams) and will not be considered here. Fig. III graphs some doublet parameters against particle momentum.

Elastic and Inelastic Electron and Positron Experiments

1. Elastic Scattering

The scattering of electrons off the nucleon, initiated by Hofstadter at Stanford and continued to higher energy and momentum transfers at Cornell and C.E.A. has provided a direct measure of the mean charge radius and led to the speculation of the existence of heavier mesons. The experiment is simple in principle, detecting the scattered electron with a spectrometer, which can resolve the elastic event from the inelastic pion continuum (for 5 BeV incident electrons ≈3% energy separation). In fact there is no substitute for electron detection since at energies above 3 BeV it is possible to produce an inelastic proton with the same angle and energy as the elastically scattered proton. There are two distinct methods of performing electron experiments at an electron synchrotron.

i. Internal Target

The internal target consists of a thin vertical pencil of hydrogen which is placed in the synchrotron beam. The circulating beam is only a few mm high and this produces a target of very small dimensions - a point source, which is ideally suited to a single quadrupole spectrometer as a detector. The effective target length is typically greater by a factor of 10 to 100 because the circulating beam makes multiple traversals of the target. At forward angles, the single quadrupole magnet together with threshold gas Cerenkov counter and shower detector is an efficient electron detector (C.E.A., - 12 in bore, ℓ = 48 in, G = 1 Kgauss/in, D.E.S.Y., - 11.3 in bore, ℓ = 39 ins, G = 2.5Kgauss/in). At larger angles, the discrimination of the lower energy scattered electrons from pions is difficult due to the reduced shower efficiency. The detection of the electron and proton in coincidence using two spectrometers eliminates the pion background.

ii. Extracted Beam

The monoenergetic extraction of approximately 70% of the circulating beam at C.E.A. enables electron experiments to be performed well away from the background radiation of the synchrotron, and provides easy access for complete angular distributions. Unfortunately the single quadrupole is no longer as effective since an extended target is now required to compensate for the loss of multiple traversals. One possible detection scheme requiring no magnetic analysis is to place spark chambers on either side of the hydrogen target and select the elastic events by coplanarity. Apart from the background problem, some selective triggering is essential otherwise the low q^2 events are dominant.

The detection of the electron alone can be accomplished by a spectrometer arm which utilises the decrease of electron angle with momentum by insertion of a horizontally focussing quadrupole close to the target followed by a uniform field bending magnet to partially focus the electrons, and eventual formation of a parallel beam for Cerenkov selection. A typical system might conceivably consist of four quadrupoles and two bending magnets to cover the full scattered energy range of the 5.5. BeV incident energy.

2. Inelastic Electron Studies

The study of inelastic electron experiments should in principle provide information of the electromagnetic form factors of short lived particles or resonances, although the extraction of this information is not straightforward. These experiments are difficult and so far investigators in this field (Stanford, C.E.A.) have been limited to detection of only one of the detection products, which does not provide any basically new information over that which can be extracted from photoproduction experiments. The determination of the energy and polarisation of the virtual photon is measured by the momentum vector of the scattered electron (similar to γ-ray tagging). The final state of the interaction is selected by detection of one of the reaction products,

e.g. $e^- + p \rightarrow p^* + e^-$ $p^* \rightarrow \pi^0 + p,\ \pi^+ + n$ etc.

The elastic electron spectrometer can select the inelastic electron, the counting rates at the same angle and energy are similar in the two processes. The detection of the secondary particle however introduces a severe limitation on the counting rate unless the detector occupies a large fraction of the total solid angle. One solution is to place a large aperture bending magnet on the opposite side of the spectrometer.

Photoproduction Experiments

In what follows, only photoproduction experiments using the bremsstrahlung beam will be considered, with no prior selection of the photon energy.

1. $\gamma + p \rightarrow x^0 + p$ ($x^0 \rightarrow$ neutrals, charged + neutrals, π^0, η^0)

This experiment is important in the study of higher resonant states of the proton and will be a very powerful technique by using the recoil proton in association with one of the secondaries to establish the neutral particle and the centre of mass energy of the reaction. The proton momentum is determined by a spectrometer consisting of a quadrupole pair and bending magnet for Cerenkov selection and momentum definition. The energy of one of the neutrals can be detected by a Cerenkov counter or high Z-plate spark chamber. Single charged pion production can be studied using the same technique.

2. Pair Production etc.

$\gamma+p \rightarrow X^{+}+X^{-}+p$
$\rightarrow X^{o}+p$ ($X^{o} \rightarrow Y^{+}+Y^{-}$, e.g. ρ^{o} production)

Pair production experiments are certainly among the most elegant of photoproduction experiments. The production of wide angle electron pairs and the production of muon pairs provides a separate test of Q.E.D. to small distances (.16f^{-1} for 5 BeV photons on carbon). The photon energy and momentum transfer is generally determined by measuring the angles and momenta of the charged particle pair.

The half quadrupole placed on either side of the beam line permits measurements close to the target. It is generally necessary to bend the particles away from the beam direction by inserting the target in a uniform magnetic field.

The study of pion pairs etc. to investigate the pion resonances at photon energies above 1 BeV will require detailed experiments based on the preliminary reports from the C.E.A. bubble chamber data (Crouch et al. to be published). This experiment requires accurate knowledge of the momenta and angles of two of the charged particles suggesting spark chambers inside a uniform magnetic field placed on either side of the beam line. This experimental arrangement is not very selective (large counter sizes giving high accidental coincidence rates) and it is probably better to include some form of focussing in one arm of the spectrometer. A large aperture quadrupole focussing in the horizontal plane to match the geometry of the bending magnet is a possible solution. The same experimental arrangement can be used for the study of other charged meson pairs, e.g. φ.production.

Production of Strange Particles

The study of strange particle photoproduction with counters in the photon energy range from 1 - 5 BeV will be difficult due to the large number of reaction channels producing short lived compound particles, e.g. K^*, Y^* etc. Past experiments have measured two body $K^{+}\Lambda^{o}$ and $K^{+}\Sigma^{o}$ production, where it was possible to determine the reaction by the properties of the K^{+} only. For $K\Sigma$ studies, it was necessary to perform a yield subtraction technique giving large statistical errors due to small differences.

At photon energies much above 1.5 BeV, it is very difficult to resolve the two processes by detection of the K meson only, and of course other processes like K pair production, K* and three particle production begin to contribute at the higher photon energies. One possible solution is K-meson tagging where the K-meson is detected and the properties of the proton from the hyperon decay are recorded.

Although there is spatial overalapping between the cone of the Λ^os from the Σ^o decay and the Λ^o for a K meson momentum and angle, the energy and position of the Λ^o and hence of the proton from the Λ^o decay are unique with respect to the K meson direction and momentum.

The charge decay of the Λ^o above 2 BeV/c has a maximum opening angle of 25° and it should be possible to detect the Λ^o alone by these charged decays, relying on accurate location of the decay vertex outside a target for separation from multipion events. This same technique applies for the detection of K^o ($\pi^+\pi^-$ decay $\sim$ 30%) events. Although some preliminary studies in the BeV region may be made with counter hodoscopes, strange particle physics at NINA should be undertaken with spark chambers and momentum analysis.

K meson detection requires Cerenkov selection separating kaons from pions and protons in the 1 - 4 BeV/c region. A threshold detector may be sufficient for a coincidence experiment,otherwise angular selection will be required for selective K-meson tagging, again requiring the quadrupole doublet for formation of a parallel beam. K^+ detection should be interesting at small angles (Drell effect and Morovsik type pole extrapolations) where the half quadrupole will be required (e.g. at 3 BeV incident photon energy, the production of the K^+ meson in the K Λ, Σ , process at 30° in c. of m. corresponds to 10° in the laboratory frame). The vertical bending magnet is a possible detector of the hyperon kinematics.

Strange particle studies of more than two secondary products can be kinematically considered as two compound-particle production, and the experimental arrangement should be similar to the above.

Conclusions

Although little attention has been given to many of the important experimental difficulties, e.g. target backgrounds, magnet wall scattering, etc., generally demanding more detailed information it is fairly clear that NINA's experimental programme must be geared to high precision experiments. If these are to be accomplished, then the number of deflecting magnets should not be much smaller than the number of quadrupole detection magnets.

It is proposed that the laboratory standardise on the DESY type 12 inch diameter quadrupole of length typically 40 inch and gradient $\sim$ 2 Kgauss/in. Provision should be made in at least two of these magnets for passage of the beam close to the quadrupole gap. For small angle work two half quadrupoles are the minimum requirement.

Two large aperture quadrupoles of 14 - 16 ins diameter and field gradient of $\sim$ 1.5 Kgauss/in are very suitable for the detection of low yield low momentum ($\sim$ 1 BeV/c) particles at backward angles. These could be used either individually or as a quadrupole pair. The 6/8 inch diameter quadrupole of 4 Kgauss/in and typical length of 40 ins is suggested for the highest momentum studies. Since these momenta only occur at small angles (up to 10°) provision must be made for beam access.

The design of uniform field bending magnets which will be required at NINA should be considered in association with spark chamber requirements. Momentum determination after quadrupole selection can be obtained from the position and angle of the incident and outgoing magnet trajectories and therefore gap widths of 6 ins are sufficient to accommodate the narrow dimension of the beam cross-section after passing through the quadrupole. If the bending magnet is exposed directly to the target then the momentum is measured by the curvature of the particle trajectory inside the magnetic field. The location of the spark chambers inside the field region requires gap heights of 10 - 12 ins for easy access and handling facilities. Some of the larger aperture magnets will have to be designed and built for particular experiments, but magnets of 10 - 12 ins air gap should be available as standard equipment since these are sufficient for many experiments. Standard track sampling chambers (assumed negligible R.L.) placed in a 10 K gauss field of length $\sim$50 ins give 1% error in momentum for a 2 BeV/c particle (A. Roberts, S.S.C.5, 1964).

Other Magnets Required

1. External Beams

A magnetic transport system will be required for the extracted electron beam. Although the details of this are not yet determined, the transport system will probably consist of 4 quadrupoles and two bending magnets of 4 in aperture. For other external electron beams, e.g. converted positron, low intensity γ-rays etc., more 4 in quadrupoles will be required. Conventional quadrupoles of low power consumption are sufficient for these systems.

2. Clearing Magnets

Clearing magnets are required for sweeping electrons and positrons out of the bremsstrahlung beam. Permanent magnets are recommended for this because of their simplicity and ease of location. Four to six long general purpose magnets (3 in x 20 in) are recommended for NINA which can be used for special beam hardening conditions or for small deflections of high energy beams.

3. Pair Spectrometer Magnet

It will be necessary at some stage after or during the initial operation of NINA to calibrate the machine energy and determine the bremsstrahlung spectrum of the multi BeV photon beam. An accuracy of $\sim \frac{1}{2}$% in the photon energy can be obtained by a counter hodoscope and a magnetic spectrometer analysing the electron positron pair. Such a system should be permanently maintained if experiments are to be performed using polarised photons in order to check the degree of polarisation.

Power Supplies

The power supplies will utilize silicon rectifiers and series transistors, which should provide current regulation to 0.1%. For the higher power units, self-saturating reactors and silicon diodes may be required. Initially it was hoped that these supplies would occupy a small volume and could all be located by the experimental magnets, but this now seems unlikely and the D.C. supplies will probably have to be piped into the experimental hall. The power supplies will probably be made up of standard block units of typically 25, 50 and 100 KW.

Coil Structure

It is intended that the magnet coils of the experimental detection magnets are vacuum impregnated for ruggedness and trouble free operation. Standard coils should be sufficient for the small compact 4 in beam transport quadrupoles.

Magnet Mounting

The magnets should be mounted by three precision jacks on individual mobile stands to accommodate the beam height of 60 ins and the jack should have a ± 2 in adjustment. It is recommended that several large ex-naval gun carriages be obtained on which magnet platforms can be mounted, for easy accurate angular rotation.

Magnet Storage

It is proposed that some space is available on or near the experimental hall well away from the experimental area, where the experimental magnets can be safely located and available for setting up spark chamber experiments etc. while the machine is operating.

EXPERIMENTAL MAGNETS

Quadrupole Magnets.

Type	Aperture		Magnet Length	Weight Tons	Max.Field Gradient	No.
C.E.A.						
Conventional		4 in 10.2 cm	12 in 30.5 cm	½		27
"		6 in 15.2 cm	22 in 56 cm	-	3 Kg/in 1.18 Kg/cm	4
"		8 in 20.3 cm	36 in 91.5 cm	4	.53 Kg/cm	4
"		12 in 30.5 cm	48 in 122 cm	10	1.07 Kg/in .41 Kg/cm	8
Half		12 in 30.5 cm	48 in 122 cm	7	1.07 Kg/in .42 Kg/cm	2
Lozenge	6 in x 24 in 15.2cm x 61cm		48 in 122 cm	8		2
D E.S.Y.						
Q.D.	2.2in x 8.6in 5.5cm x 22 cm	6.3 in 16 cm	21 in 54 cm	1.5	5 Kg/in 2 Kg/cm	10
Q.B.	2.2in x 8.6in 5.5cm x 22 cm	6.3 in 16 cm	41 in 105 cm	3	5 Kg/in 2 Kg/cm	11
Q.A.	4 in x 15.7in 10 cm x 40 cm	11.4in 29 cm	41 in 105 cm	10	2.7 Kg/in 1.1 Kg/cm	11
Q.C.	5 in x 19.5in 12.5cm x 50cm	14 in 35.5cm	26 in 66 cm	9	2.25 Kg/in 0.9 Kg/cm	2
Half	5 in x 19.5in 12.5cm x 50cm	14 in 35.5cm	26 in 66 cm	5	2.25 Kg/in 0.9 Kg/cm	1
NINA (Proposed)						
Conventional		4 in 10.2cm	24-30 in 71-75 cm		5 Kg/in 2 Kg/cm	As required
D.E.S.Y. B	2.2in x 8.6in 5.5cm x 22 cm	6.3 in 16 cm	41 in 105 cm		5 Kg/in 2 Kg/cm	4
Half	2.2in x 8.6in 5.5cm x 22 cm	6.3 in 16 cm	41 in 105 cm		5 Kg/in 2 Kg/cm	2
D.E.S.Y. A	4 in x 15.7in 10cm x 40cm	11.4in 29 cm	41 in 105 cm	10	2.7 Kg/in 1.1 Kg/cm	6
Half	4 in x 15.7in 10cm x 40 cm	11.4in 29 cm	41 in 105 cm	10	2.7 Kg/in 1.1 Kg/cm	-
D.E.S.Y. C	5 in x 19.5in 12.5cm x 50cm	14 in 35.5cm	26 in 66 cm	9	2.25 Kg/in 0.9 Kg/cm	2

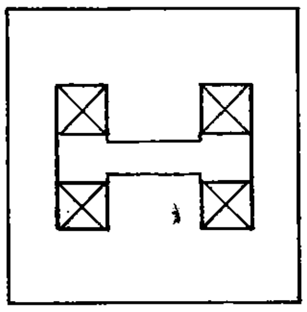
EXPERIMENTAL MAGNETS

Uniform Field Magnets

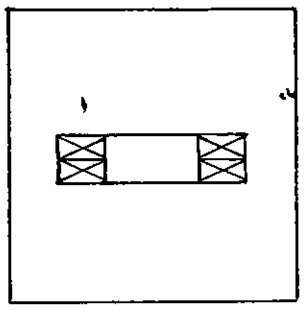
Type	Aperture		Magnet Length	Weight Tons	Field Kgauss	No.
C.E.A.						
Clearing	3 in x 10 in 7.6cm x 25 cm		72 in 182.8cm	11	18	8
ditto	3 in x 3 in 7.6cm x 7.5 cm		10 in 25.4 cm	0.1	Permanent	20
ditto	10 in x 22 in 25.5 cm x 56cm	-	48 in 121.9 cm	38	19	2
25°	6 in x 12 in 15 cm x 30.5cm	-	72 in 182.8 cm	18		1
Vertical	11 in x 16 in 28 cm x 40.6cm	-	48 in 121.9 cm	35		1
	3 in x 5 in 7.6cm x 12.7cm	-	36 in 91.4 cm	2		1
	3 in x 12 in 7.6cm x 30.5cm	-	42 in 106.7 cm	10		4
	6 in x 18 in 15.2cm x 45.7cm		36 in 91.4 cm		18	1
D.E.S.Y.						
M.A.	6.5 in x 20 in 17 cm x 51 cm	-	53 in 133 cm	20	21 @ 400 KW	5
M.B.	4 in x 13.5 in 10.5cm x 33 cm	-	40.5 in 103 cm	7	21 @ 300 KW	10
NINA (Proposed)						
Clearing	3 in x 20 in 7.6cm x 50.8cm	-	48-72 in 120-180cm		20	4-6
ditto	3 in x 3 in 7.6cm x 7.6cm	-	12 in 30.5 cm		Permanent	10-12
	4-6in x 24-30in 10-15cm x 60-75cm	-	50 in 127 cm		20	6
	10-12in x 20-30in 25-30cm x 50-75cm		48 in 130 cm		18	4
Vertical	20-30in x 10/12in 50-75cm x 25-30cm	-	48 in 130 cm		ditto	1-2

MAGNETS. FIG I.

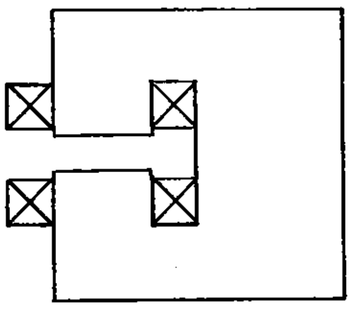
UNIFORM FIELD BENDING MAGNETS.



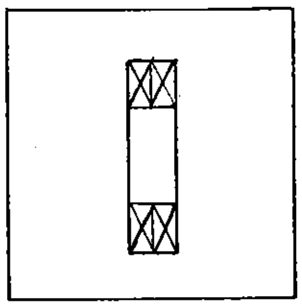
(a) H TYPE.



(b) WINDOW FRAME

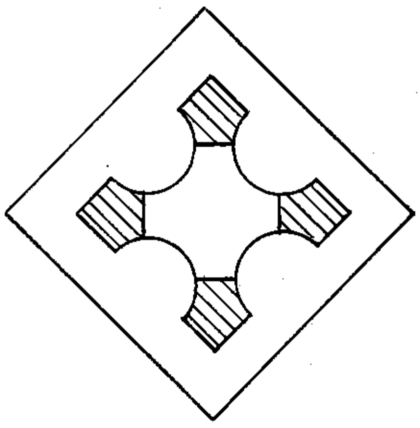


(c) C MAGNET.

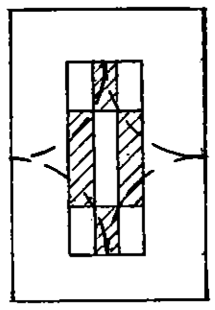


(d) VERTICAL DEFL.

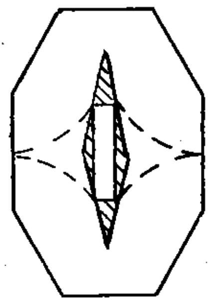
QUADRUPOLE MAGNETS



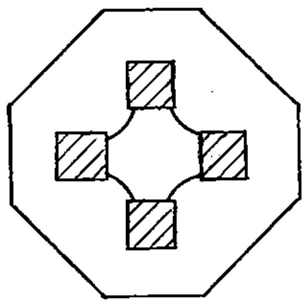
(e) CONVENTIONAL.



(f) PANOFSKY.

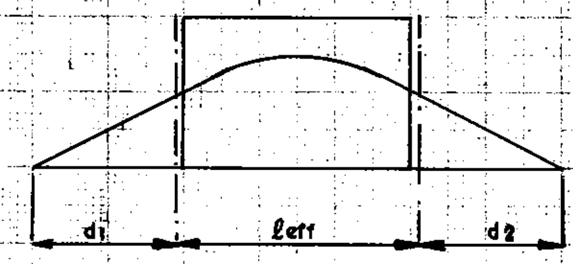


(g) LOZENGE.



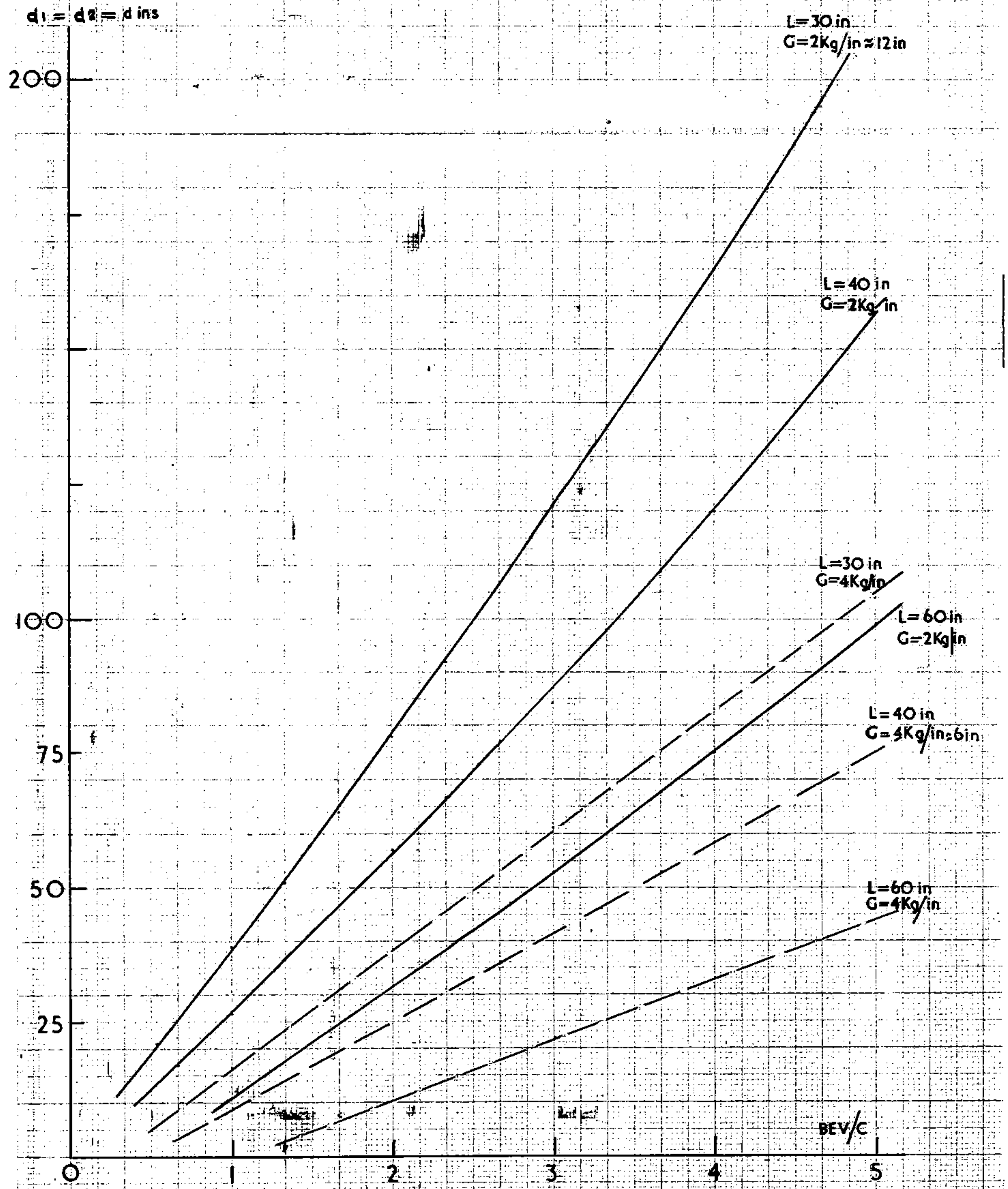
(h) DESY.

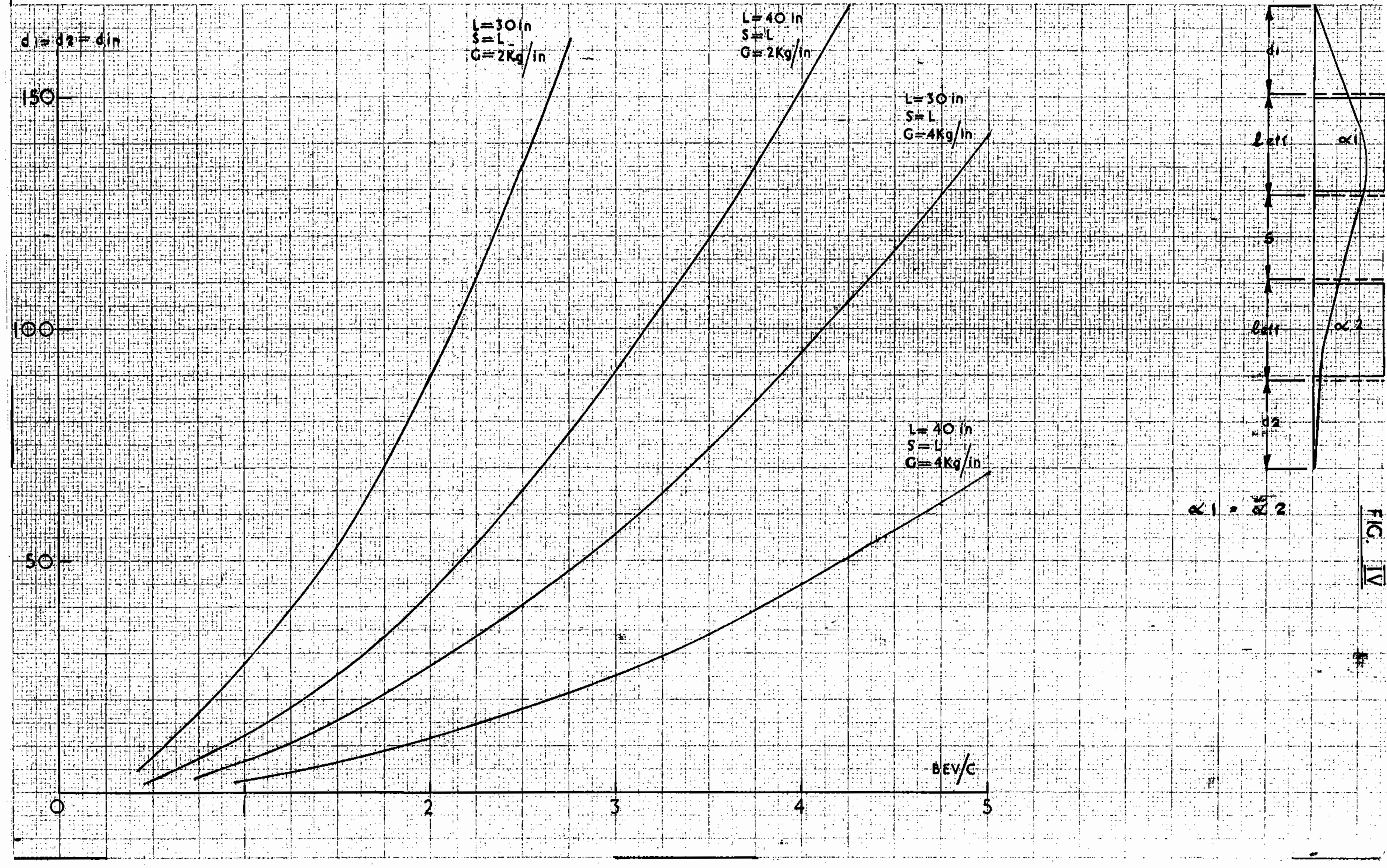
FIG. III



$\alpha(d_1 d_2 - \frac{1}{\alpha^2}) \tan \alpha l = d_1 + d_2$ FOCUSSING CONDITION

$\alpha \tan \frac{\alpha l}{2} = \frac{1}{d}$ $(d_1 = d_2 = d)$





d1 = d2 = d in
150
100
50
0
1
2
3
4
5
BEV/C
L=30 in
S=L
G=2Kg/in
L=40 in
S=L
G=2Kg/in
L=30 in
S=L
G=4Kg/in
L=40 in
S=L
G=4Kg/in
d1
ℓ eff
α1
S
ℓ eff
α2
d2
α1 = α2

FIG. IV