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A PROPOSAL FOR AN OPEN MAGNET SYSTEM FOR THE ISR EXPERIMENTAL REGION

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1. INTRODUCTION

Hyams and O'Neill have recently proposed a large general purpose magnet system for use at one of the intersection regions at the ISR. We have been considering if this is the optimum design for our needs.

One of us (F.K.) has proposed a magnet system with a similar field configuration, but with rather different characteristics. Section 2 is devoted to a formal description of his proposal. A preliminary description of the Hyams-O'Neill system has already been distributed.

The finalization of the design of such a general purpose magnet will depend very much on the wishes of the prospective users. In order to make this easier and perhaps stimulate new ideas, we will give, in section 3, a short comparison of the two systems, setting down (almost) impartially the advantages and disadvantages of both.

2. DESCRIPTION OF THE PROPOSED SYSTEM

2.1. We are considering a magnet with the following characteristics:

a) The magnetic fields are vertical.

b) There is complete compensation of the circulating proton orbits. Protons enter, intersect and leave the experimental region in precisely the same way with, or without, magnetic fields switched on.

c) In and around the median plane, there is a minimum of obstruction, so facilitating the setting up of bulky experimental equipment.

d) A flared vacuum chamber with a thin end face and moveable downstream vacuum pipes enables protons of beam momentum to escape at angles as low as 8 milliradians.

e) The power consumption in conventional coils will be reasonable. Alternatively, if higher fields are required, a superconducting coil of simple construction would be possible.

2.2. Compensation in the sense of 21b may be achieved by a number of alternating magnetic fields B , which integrated along the orbit S , yield

$$\int_{S_1}^{S_2} B\,dS = 0 \quad \text{and} \quad \int_{S_1}^{S_2} dS \int_{S_1}^{S} B\,dS = 0 .$$

If S_1 is the centre of the intersection region then the above must be true when S_2 is either the entry or the exit. With piecewise constant B, it may be shown that a minimum of 5 fields are required.

We will describe further the nature of the magnetic fields which the circulating protons encounter when they cross the long straight section. Remember, this section extends 7 m upstream and 10 m downstream from the centre of the intersection region.

The figure 1b shows schematically the magnetic fields and Fig. 1a the approximate orbit. Notice that the changes in the field are not abrupt, in particular with the open type magnets. Large fluxes are present in the central field region and in the downstream bending region. As they are opposite we take advantage of this situation by using a unique coil system for both fields. This principle creates automatically an open magnet system, thus meeting the design consideration 2.1.c and to some extent 2.1e. Figs 2a,b,c show the magnet. Because the intersection angle is 15°, the upstream orbit is only in the fringing field of the downstream magnet of the other orbit. Thus one is able to place compensators in this region. Because of space limitations and the desire to have the largest possible area for the central field, a septum magnet, which is able to project into the edge of the central field region is used. The top half of the magnet rests on pillars. The vacuum pipe will be designed so that the minimum clearance is guaranteed whether the magnetic field is switched on or not. For a given conservative clearance the minimum escape angle is 18 mrad in the median plane and 8 mrad in the vertical direction. The downstream vacuum pipe will be moveable by means of bellows to push the pipe so that on one side smaller escape angles are favoured, at the expense of course of the escape on the other side. A displacement of 30 mm or more at the end face of the flared vacuum chamber may be envisaged, which means a gain of at least 10 mrad.

One downstream ISR magnet should be of the closed type, so that both protons, scattered at small angles will be analysed with reasonable lever arm and could be even further deflected with auxiliary bending magnets.

2.3. Tentative parameters of proposed magnet system (Two versions)

	This proposal	High field	Unit
Bending power in central region $B \cdot r_{eff}$	1.7	2.4	Tesla m.
id. in downstream magnet $B \cdot L_{eff}$	4.8	6.8	Tesla m.
Total steel	1200	1700	ton
Total copper	121	167	ton
Total power	3	6.6	MW
Total attractive force	2000	4000	ton
Total stored energy	20	44	MJ

2.3.1 Central magnet region

	This proposal	High field	Unit
Field	0.5	0.7	Tesla
Effective pole radius	3.4	3.4	m.
Height of gap	3	3	m
Effective flux	17	24	Weber
Stored energy	10	20	MJ
Amp. turns	$1.2 \cdot 10^6$	$1.75 \cdot 10^6$	A
Current density	$3 \cdot 10^6$	$3.5 \cdot 10^6$	Am^{-2}
Coil section	$0.5 \cdot 0.4$	$0.5 \cdot 0.5$	m^2
Power	1.24	2.1	MW
Copper	59	73	ton.

2.3.2 Downstream magnet

	This proposal	High field	Unit
Field	1.2	1.7	Tesla
Effective length	3.5	3.5	m.
Effective width	2.2	2.2	m.
Height of gap	1	1	m.
Effective flux	9.2	13	Weber
Stored energy	5	12	MJ
Amp. turns	10^6	$2 \cdot 10^6$	A
Current density	$3 \cdot 10^6$	$4 \cdot 10^6$	A m^{-2}
Coil section	0.16	0.25	m^2
Power	0.66	1.76	MW
Copper	31	47	ton.

2.3.3 Main compensator

	This proposal	High field	Unit
Field	2	2.8	Tesla
Effective length	1.5	1.5	m.
Effective width	0.2	0.2	m.
Height	0.05	0.05	m.
Effective flux	0.6	0.9	Weber
Amp. turns	$8 \cdot 10^4$	$2.5 \cdot 10^5$	A.
Current density	$3 \cdot 10^7$	$3 \cdot 10^7$	A m^{-2}
Power	0.15	0.5	MW

2.4 Operation of the magnet

The field in open type magnets is not homogeneous and one has to live with it. The complete compensation 2.1b allows different beam energies to be chosen in the storage rings. Due to saturation effects it is desirable to switch on the magnet first, before sending the first trial stack into the storage ring. Some additional, small, electronically controlled steering magnets may be required, although in principle, in the absence of saturation effects automatic stability is achieved if all coil currents are connected in series. A central hole in top and bottom poles will be made to facilitate photography, and a number of peripheral small holes will be made to accommodate light guides or photomultipliers. The poles of the downstream bending magnets will have holes where the deflection is largest. All pole faces will have T-slots, so they may serve as bed plates to clamp experimental (non magnetic) equipment.

The high field version is tentative. It will be appreciably more expensive and the problems of flux equalization and stray fields start to be rather complicated. A careful study of their effect on the ISR performance must be made. This extra effort and cost needs to be justified.

3. A COMPARISION OF THE PROPOSED SYSTEM WITH THAT OF THE HYAMS-O'NEILL SYSTEM

3.1. Similarities.

i) Both systems use five vertically directed magnetic field regions per orbit:

a) A large circular field centred on the intersection region.

b) Two downstream high field regions.

c) Two main compensators to match the system to the ISR downstream, and

d) Two composite low field compensators to match the ISR upstream.

ii) Both use a flared vacuum pipe so that particles entering the downstream magnets emerge normal to the surface of the vacuum vessel.

Figs 3 a and b show a comparison in the plan view.

3.2. Differences in magnetic field configuration

The main differences are in the realization of the field configuration and in the field strengths. The structural differences are shown in Figs. 4 a and b which correspond to vertical sections.

3.2.1. The field configuration

i) The Hyams-O'Neill system. The magnetic field regions are completely independent, and each has its own return path. Emphasis is placed on field uniformity. This leads to a construction of iron enclosed solenoids, with the iron removed and the normal coils replaced by thin current-carrying sheets where the particles have to pass from the central region to the downstream magnets. (An alternative, open structure, design is also suggested for the downstream magnets). The two compensators are placed in field free cavities in the downstream field regions.

ii) The Krienen system. This is a composite magnet system in which the return field from each region is used to provide the magnetic field in its adjacent region with a consequent reduction in cost. There are no iron return paths around the system, so it is more accessible and more easily extended. The price of this is the non-uniformity of the fields.

3.3. Momentum resolution in the central region

Neither solution is better for all types of experiments. (The high field version is better for more types of experiment, it is better for low transverse momentum secondaries.). The areas of both fields are equal in the horizontal plane. Hyams and O'Neill have twice the vertical height in the field volume, but only half or one third of the field strength. Fig. 5 shows the relative accuracy of the two systems as a function of the solid angle acceptance. Two curves are given for the lower field version of the Krienen magnet. The solid curve assumes spark chambers being placed only in the magnetic field volume. The broken curve can be obtained if chambers are placed at up to 3 metres outside the magnetic field, thus doubling the observed trajectory length.

3.4. Background.

Both proposals have flared vacuum chambers with thin end windows. The Hyams-O'Neill central magnet has 3 mm of aluminium in the path of the emerging particles. For a 400 mbarn cross section for Al, this gives a 1%

probability that a given particle interacts;while not disastrous, this is better avoided if possible. Most of these events will be rejected in analysis because they do not have a unique vertex.

3.5. Acceptance in the downstream regions

The table below shows a comparison of the two Hyams-O'Neill proposals and the Krienen proposal.

	Hyams-O'Neill (open)	Hyams-O'Neill picture frame	Present Proposal
Field strength	1.0 T	0.6 T	1.2 T or 1.8 T
Field length	3 m	5 m	3.5 m
Observation length	6 m	5 m	5 m(greater at some angles)
Field height	2 m	3 m	1.0 m
Effective field width	1.8 m	1.8 m	2.2 m
Minimum angle (vertical)	8 mr	8 mr	8 mr
Minimum angle (horizontal)1)	18 mr	18 mr	8 to 28 mr
Maximum acceptance (horiz.)	2 × 120 mr	2 × 90 mr	2 × 140 mr 2)
Maximum acceptance (vert.)	2 × 130 mr	2 × 165 mr	2 × 65

Notes: 1) This assumes the Terwilliger scheme is not used. The smaller angles in the Krienen table are simply due to the flexible vacuum pipe and so can also be achieved in the Hyams-O'Neill system.

2) This limit refers only to the nominal limit of the field region. There is no physical obstruction which limits the angle.

FIGURE CAPTIONS

Fig. 1a - Showing the displacement of the orbit of a 25 GeV proton in the lower field version of the magnet. (0.5 T in the central region).

Fig. 1b - Showing the magnetic field sequence encountered by one of the ISR beams crossing the magnet.

Fig. 2) - Showing the construction of the magnet.
a) - Plan view of the magnet.
b) - Showing the section S_1 S_2 of the magnet.
c) - Showing the end view of the magnet.

A : The circular central field region
B : The two rectangular downstream regions.
C : The two main compensators.
D : The two composite upstream compensators, each of which contains two oppositely directed field regions.
E : The adjacent ISR (F_2) magnets.
F : The pillars.
G : The relevant parts of the vacuum tank.
H : coil of the central field.
I : Coil of the downstream field.
J : Coil of the main compensator.
K + L : The connecting yoke between the central, downstream and compensator field regions.

Fig. 3 - Showing a comparison in the plan view of
a) - The Hyams-O'Neill magnet.
b) - The present proposal.

Fig. 4 - Showing a comparison in the section along the two downstream beam orbits of
a) - The Hyams O'Neill magnet.
b) - The present proposal.

Fig. 5 - Showing the variation in accuracy of momentum measurement as a function of elevation Θ. Note that in both proposals, the error is almost constant up to $\cos\Theta = 0.45$. This includes, with full efficiency, all scattering angles up to 460 mr relative to the beam directions.

Fig 1a

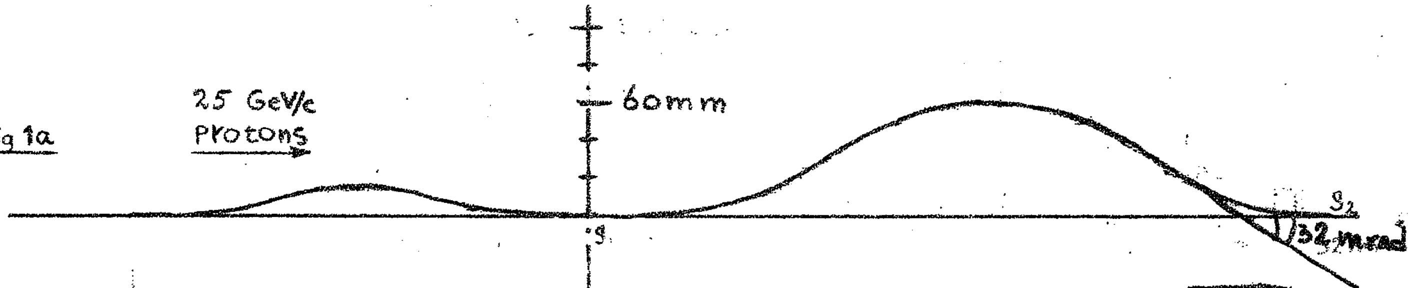


Fig 1b

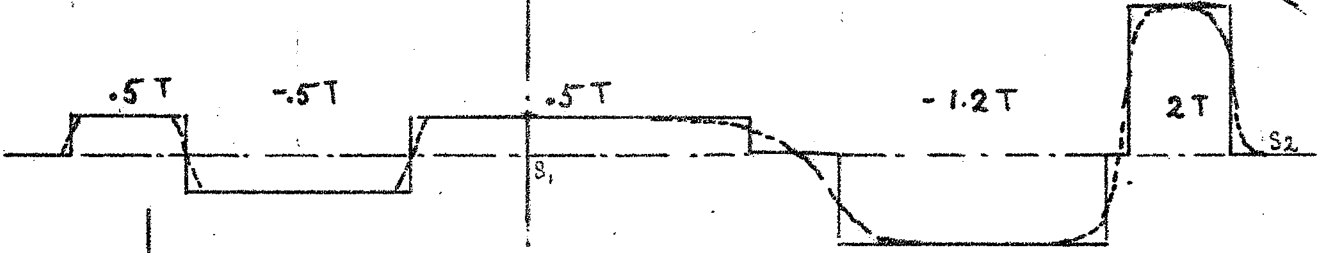


Fig 2c

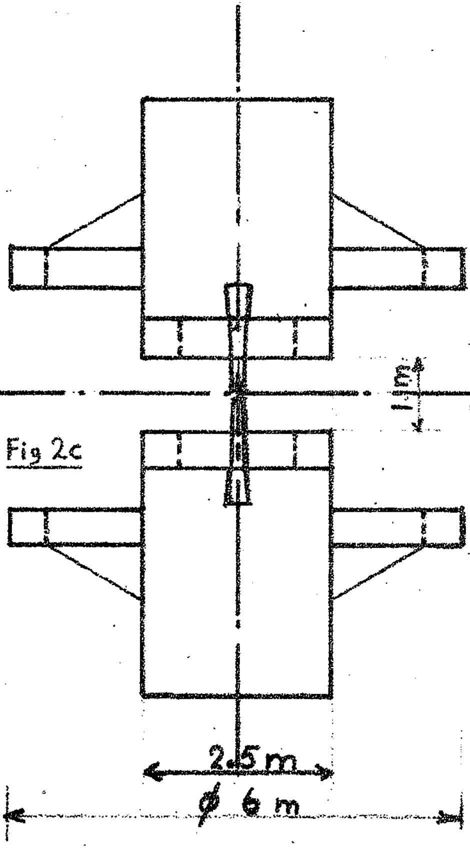


Fig 2b

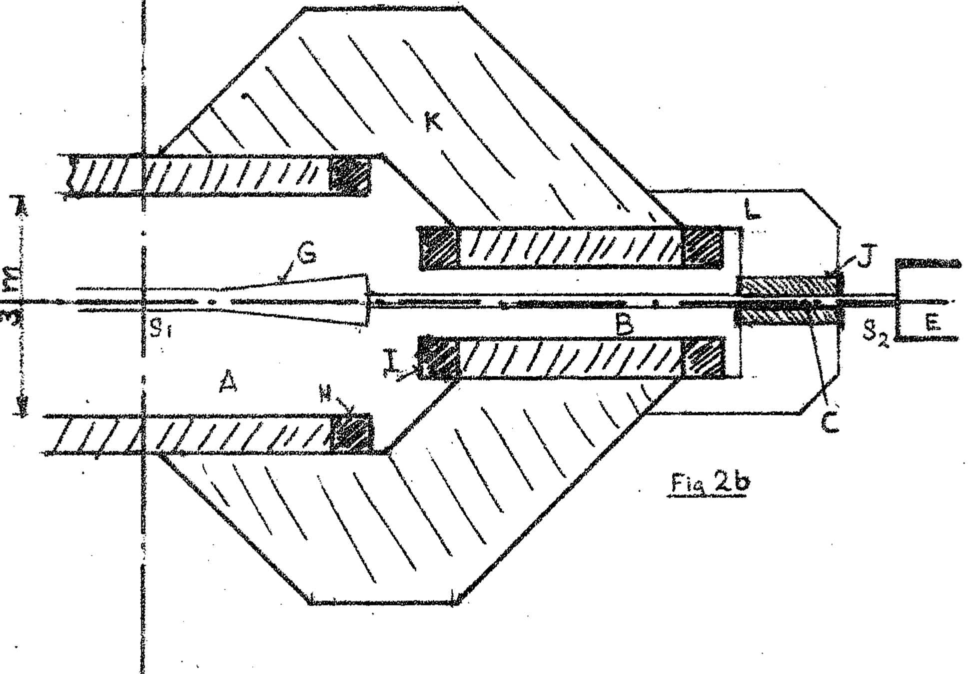
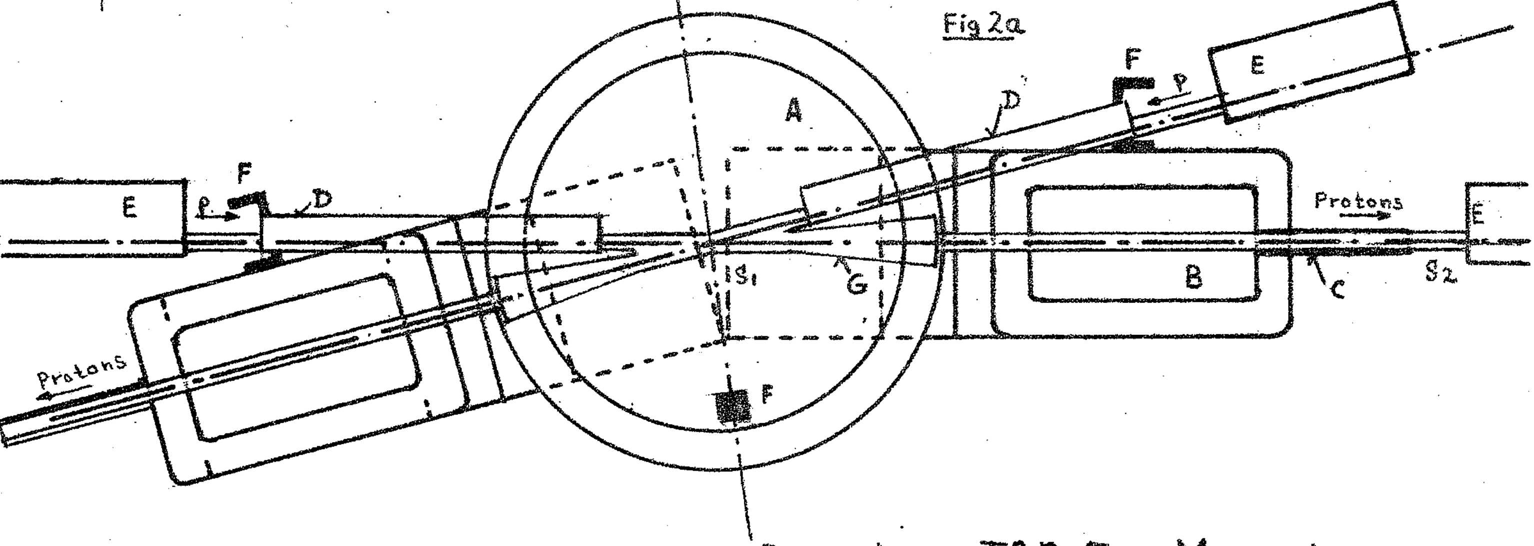


Fig 2a



Open type ISR Exp. Magnet

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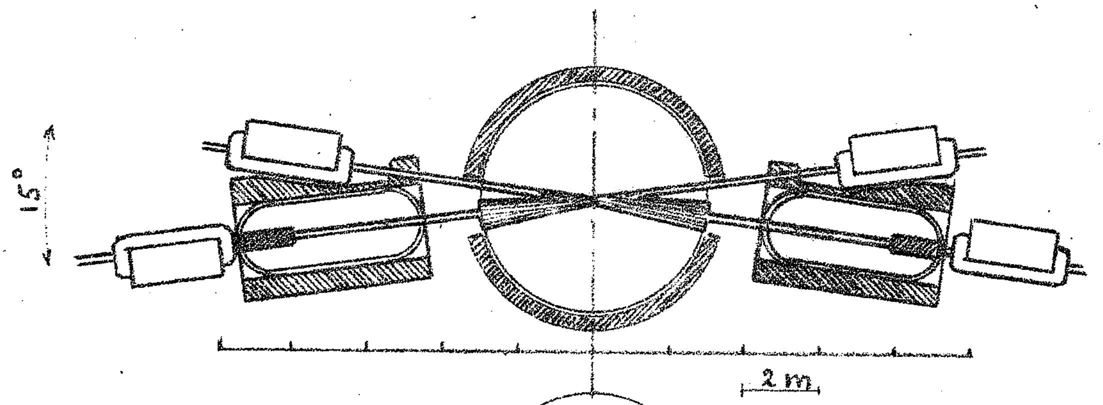

Fig 3a

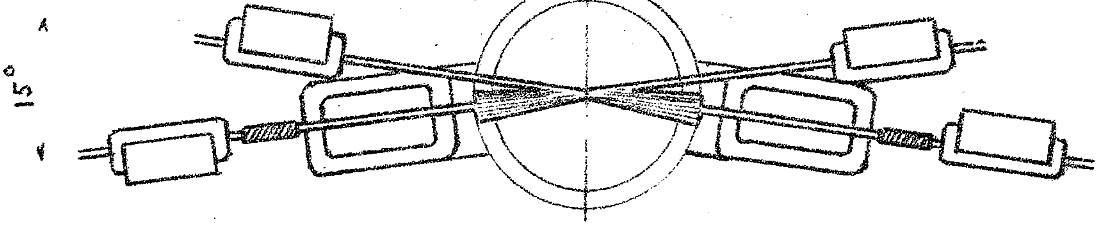

Fig 3b

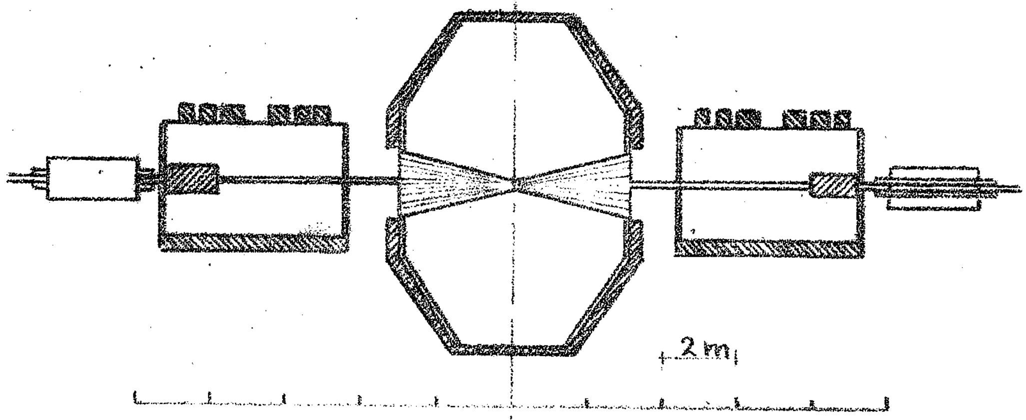

Fig 4a

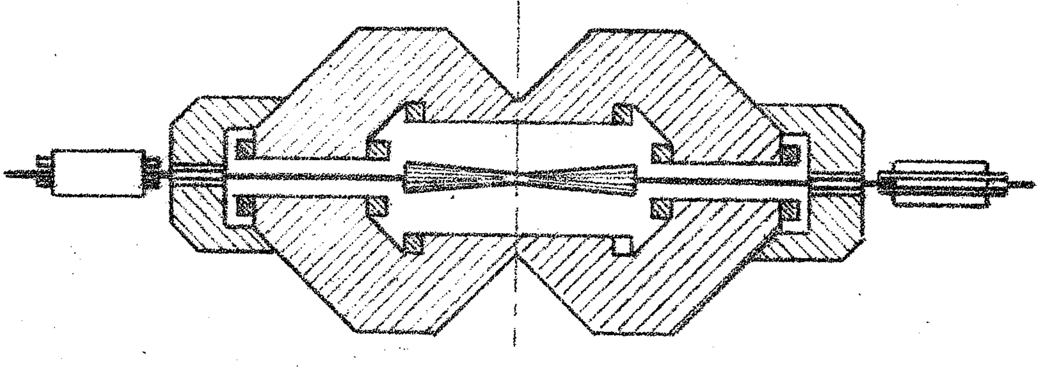

Fig 4b

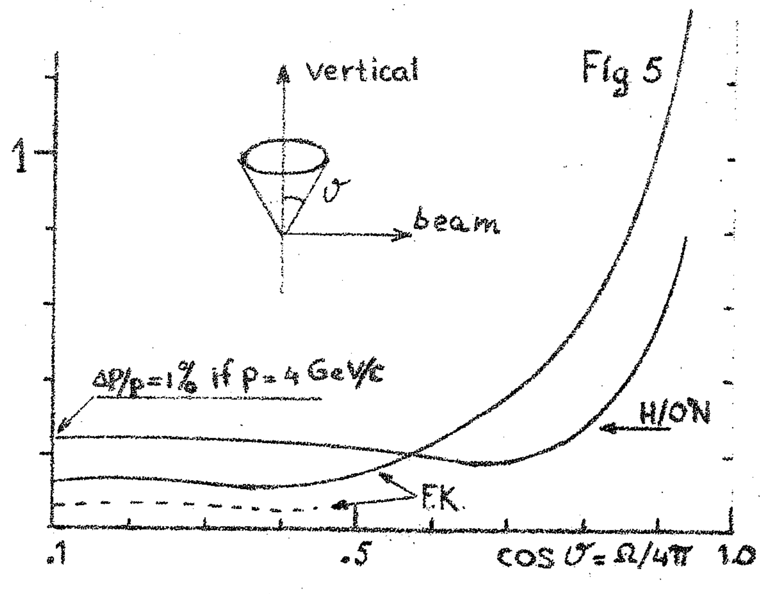

Fig 5

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