DRAFT (For internal use only)

C.P.S. STRAIGHT SECTION REARRANGEMENT

A. REASONS FOR LENGTHENING OR REARRANGEMENT OF STRAIGHT SECTION :

Table I shows a rough comparison of what production angles one might expect for various types of beam from different straight sections. Data for the columns "Normal Long F" and "Normal short D" are taken from the CERN PS Users Handbook (Section J) ; that for the Normal long D has been taken from the note which forms Appendix I. F and D refer to the radial focussing and defocussing straight sections (for positive particles)of the P.S. magnet system. In general the D type section is most interesting for secondary beam production. At the higher momenta (say $p \gtrsim 4$ Gev/c) the yield of particles, for a given momentum, momentum bite and solid angle acceptance increases and maximised at 0 degree production angle (see for example, report NP/Int. 63-11) .

A very rough rule valid for low production angles is that one gains a factor of two in intensity for each degree decrease. No comparisons of intensity have been made in the table at this stage.

Of the projects given below, an extra long straight section (about 6m in total) for the South Hall, seems the attractive at first sight. It has not been possible to evaluate the implications in terms of P.S. performance labour and finance. Moreover, this project should be considered in relation to a new neutrino area and the future of ejection facilities into the South Hall. If ejection facilities continue to exist it would be interesting to separate them specially from the principal internal target straight section.

B. POSSIBLE PROJECTS :

Some of the methods of rearranging the P.S. Magnet structure are given in the report given in Appendix II. The following projects suggest themselves for study :

a) Regular Pattern (Appendix II, case A) : The proposal to have N long straight sections with N = 4, 5, 6, 7 would perhaps require 9-12 months shut-down and would probably only be useful if considered in conjunction of the complete redesign of P.S. experimental areas. This proposal is therefore rejected for the time being.

b) Local rearrangement I(Appendix II, case B) : (South Area) : Introduction of Normal Long D 100. Assume neutrino experiment remains where it is and that the length although not the position of S.S. 1 is unchanged.

c) Local rearrangement II : The introduction of an extra long straight section (total $\sim$6m) feeding beams into the South Hall. It is not obvious without further study whether the beam dynamical conditions of the P.S. can be satisfied in such a case. Hence it should be studied further.

Some future comments on straight section are given in Appendix III.

As an example of what is involved we take case b of the indroduction of a "normal long D 100".

I. DESCRIPTION OF PROJECT :

a) Justification for such a case :

- Separation of ejected beam from principal S.H. targetting facilities : possibilities for sharing
- Maximum intensity negative beams ($\sim$0 mrad) with good optics.
- An increased intensity $\sim$2 for positive beams but without the possibility of getting into the same channel when using one target for several beams.

A possible disadvantage could be that the "d" type beams might be somewhat more difficult because of the pillar position with reference to target 100.

b) General planning :

- Theory and experimental studies $\approx$	1 year
- Design and fabrication	1 year
- Possible preparation work in ring	?
- Installation	2-3 months
- Machine tests and beam investigation	1 month

c) Influence on other parts of the P.S. :

The project implies :

- Moving 14 magnet units (including exchange of M 100).
- Shortening S.S. 93 and 7, lengthen S.S. 100 (leave S.S. 6 as a present : could be discussed).
- Thus 3 new sets of bus bars.
- Thus 3 new vacuum pipes.
- Suppression of P.U. 9,3 and 7 : substitute a new small version .
- New foundations on ring beam.
- Modification of bus bars from generator house to P.S. magnet at entry to ring.
- New foundation for ejection S.S. 1 and 97.
- Hydraulic pipe work and cable,
  modifications for S.S. 1 (and S.S. 97) and the complete re-installation of the ejection system.
- Repositioning of cavity 96.
- Building : Wall modification to have space for beam transport and access.
- Survey Pillar to be moved.
- Terminal boxes to be displaced.

d) Influence on machine performance :

Such a long straight section will have an appreciable effect on the proton dynamics within the machine. The extent to which this can be compensated by the use of quadrupole lenses, and the likely effect on injection efficiency after compensation, will have to be studied both theoretically and experimentally.

As a basis for discussion we propose 5 % estimated loss of accelerated beam intensity as the level beyond which the project ceases to be interesting.

II. INFLUENCE ON EXP. PROGRAMME :

a) See table I and § B.1 (a)

b) Use of machine time for preliminary studies :

The time during which one would need full use of the machine is negligible ;

the type of test that we invisage would rather involve conditions in which the machine yields about 5 $^o/o$ less than its normally available intensity. It would be reasonable to use some 50 to 100 shifts under such conditions.

The results of this study would enable one to say whether any significient loss of average intensity, either permanant or limited to a running in period, should be expected after the installation.

c) <u>Machine Shut-down</u> :

Probably 3-4 months.

III. <u>BUDGET ETC.</u> :

a) <u>Preliminary studies</u> :

1st year (before decision on whether to implement the project or not) :

Experimental studies :	2 man years (1 scientific, 1 technical)
Hardware etc :	say 20 k S.Fr.
Theoretical studies :	1 man year (scientific)
Other Divisions :	A small amount of computer time.

Current budget could probably absorb most of this, leaving about scientific man year to be found.

b) <u>Engineering studies and design (after decision)</u>

(i) 1 Eng. 1/2 - 1 yr + help from 1 - 2 others part time.

(ii) Designer 1/2 yr and subseq. part time

(iii) a Draughtmen 1/2 yr full time + partime for a few months.

(iV) Part time help from several (3- 4 technicians)

(V) Building project 1 Engineer 1 month plus 1 other 1 month.

It might be possible to do most if not all of this from current budget- entirely dependant on the existance of other big projects.

Thus to summarise

1 Scientific)
) For $\leqslant$ 1 year
4 - 5 Technical)

c) Installation (3 - 4 months)

1 Scientific + help from others

6 technical including survey

14 Mechanics and handymen (S.B. pool + P.S. workshop)

2 Pipefitters

4 - 6 S.B. for foundations of ring beam and fast ejection

3 electricians

Building : outside contractors.

d) Costs :

(i)	Preparation of new foundations Ring	15.000.- Fr.
(ii)	Foundations fast ejection	60.000.- Fr.
(iii)	Hardware ; Bus bars	200.000.- Fr.
	Vacuum, pick up, pipework etc.	
	Terminal Box. Survey Pillar	
(iv)	Building	

e) Workshop :

Vacuum tanks and special chamber : 1 - 1 1/2 man yr.

P.U. Station mechanical parts

Miscellaneous

IV. ACKNOWLEDGEMENT :

We are indebted to J. Geibel for helpful discussions.

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TABLE I

SECONDARY BEAM PRODUCTION FROM DIFFERENT STRAIGHT SECTIONS

Particle charge or type of beam	Normal Long F	Normal short D	Normal Long D	Extra Long D 6 metre total
Negative High energy (eg. d beam)	40 m radian (4 - 18 Gev/c)	$\sim$0 mrad (4 - 18 Gev/c)	$\sim$0 m radian	$\sim$ 0
Positive High energy	80 - 100 mr (varies with p)	Worse than Long F.	Better than L.F. ($\sim$ 60-80 mr)	Better ($\sim$ 40-60 mrad)
Beam free from fringing field for best optical properties. + and - ve particles				
m_2	8.5° (with pipe)		Same as long F	~ 3-4°(with pipe)
o_2	5.5° with iron pipe and targets inside magnet unit.	No good.	Comparable with F	$\sim 3^\circ$
$k_{1/2/3/4}$		15°		5.5 without pipe
m_4	105 mrad with special magnet good acceptance *(or same accept. and twice momentum)		As for long F	Better $\sim$30mrad + Gain in accept. which is already limited by E.S. Sep. *

APPENDIX I

SECONDARY BEAMS FROM A LONG D-TYPE STRAIGHT SECTION

I. INTRODUCTION :

One of the proposals concerning possible target and ejection schemes for the East Area asks for a rearrangement of certain magnet straight sections. Magnet unit 61 should be shifted by 1.20m in the direction of SS 62-centre line towards unit 60.

The new azimuthal distance between the iron faces of units 61 and 62; so length SS 62, becomes 2.9432 m.

The location and properties of secondary beams from a standard target in the long SS 62 has been found by using Keyser's programme[1].

II. SCOPE OF THE CALCULATIONS :

One was interested at secondary beams from SS 62-long for $\pm$ (6.0, 10.0, 12.0 and 18.0) GeV/c momentum particles, emission angles -50(10)100 mrad.

To enable a somewhat more general comparison between the properties of different type of straight sections as well, trajectories has been obtained for $\pm$ 25 GeV/c and emission angles up to 130 mrad has been taken.

The results of the calculations include :

- The Michaelis coordinates (fig. 1 and 2)
- The asymptotic trajectories from SS 62 long in the East target area (fig. 3)
- The horizontal and vertical matrix transformed to the Michaelis target, representing the total effect of the magnetic fields
- The radial position of the beam inside the magnetic fields at least after every 1 m azimuthal displacement.

III. THE NEGATIVE PARTICLE BEAMS :

3.1 Optimal emission angle : The particles are focused horizontally and vertically in a wide range of emission angles.

The optimal emission angle is found where $/a_{21}/$ has its maximum. (a_{21} in the horizontal matrix at the Michaelis target is equal to the inverse focal length).

Momentum in GeV/c	Optimal emission angle in mrad.	Distance object(target)-image, called d. in m	
		hor. plane	vert. plane
- 6.0	- 10.0	6.9(7.1)	4.4
- 10.0	0.0	8.3(8.8, 9.0)	4.3
- 18.0	10.0	12.0(17.0, 20.0)	3.8
- 25.0	10.0	19.0(50.0, defoc.)	3.6

The figures in between brackets are referring to the distance d in a standard D and a long F straight section respectevely.

So at low momenta the focal properties differ little but the focusing effect remains at higher momenta in the long D section only.

3.2. Acceptable emission angles : Particles with momentum in the range of -6.0 to -25.0 GeV/c leaving the target with emission angles below -20 mrad will pass twice the inside wall of the vacuum chamber in the downstream magnet unit before going to the outside and are therefore of limited interest.

IV. THE POSITIVE PARTICLE BEAMS :

For outgoing beams, positive emission angles are of interest only.

The beams are divergent in the horizontal plane for all positive emission angles.

Beams which are not affected by the magnetic fields can be obtained at lower emission angles when the straight section is longer.

The beam data are worked out by M. Perret to obtain the trajectories lay-out drawing.

J.H.B. Madsen

Ref. 1) R. Keyser, DD/CO/63.2 : Particle trajectories in the C.P.S. magnetic field computed by a Fortran progress.
2) J.A. Geibel, MPS/EP/14, Note on high energy π beams from targets n° 1 and 2.

APPENDIX II

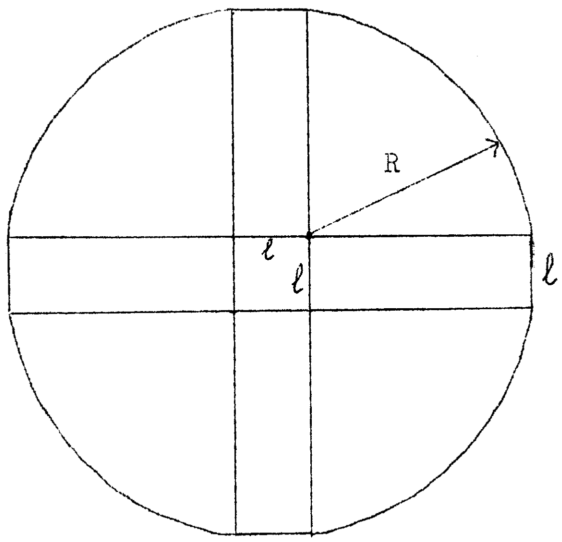
RE-ARRANGEMENT OF C.P.S. MAGNET UNITS - LONGER STRAIGHT SECTIONS

We do not consider the local shifts of a few magnet units, but rather cases where many magnets are moved in order to make several useful lengthened straight section. Possible ways of doing this fall into three broad classes, A, B, C.

A. The regular or nearly regular pattern

In first approximation we take the present CPS to be a circle of 100 m radius.

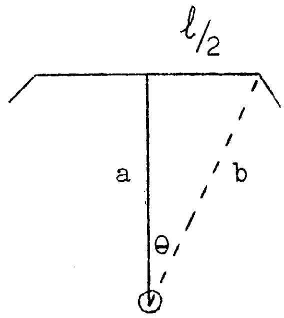
The new shape that arises if we introduce n equally spaced lengthened straight sections of extra-length ℓ each is conveniently considered by drawing the n-sided regular polygon, side-length ℓ, at the centre of the machine. Here is an exaggerated picture of the $n = 4$ case.



The corners of the ploygon are centres of the curved arcs of the resulting machine circumference. We take their radius of curvature to be R, as we shall probably have to change it from the old 100 m.

Let θ be the angle substended by half the polygon side at the centre

$$\theta = \frac{2\pi}{2n} \quad \text{or} \quad \frac{180^\circ}{n} \tag{1}$$



length of perpendicular from centre to side

= radius inscribed circle of polygon

= a

$$= \ell/_2 \cot \theta \tag{2}$$

length from centre to corner

= radius circumcircle

= b

$$= \ell/_2 \operatorname{cosec} \theta \tag{3}$$

Table I - Geometry of regular polygon

n	θ	$\frac{a}{\ell} = \frac{\cot\theta}{2}$	$\frac{b}{\ell} = \frac{\operatorname{cosec}\theta}{2}$	$\frac{b-a}{2\ell}$
2	90°	0	0.5	0.25
3	60°	.2887	.5774	.1444
4	45°	.5	.7071	.1036
5	36°	.6882	.8506	.0812
6	30°	.8660	1.0	.0670
7	25.71°	1.0384	1.1525	.0570
8	22.5°	1.2071	1.3065	.0497
9	20°	1.3738	1.4619	.0440
10	18°	1.5388	1.6180	.0396
12	15°	1.8660	1.9318	.0329
15	12°	2.3523	2.4048	.0262
20	9°	3.157	3.196	.0195

For the deformed machine the magnet units closest to the centre are at $R + a$, those furthest are at $R + b$.

Since b/ℓ is always 0.5 or more, there is no interest in keeping R unchanged at 100 m, for this would restrict the added straight section length (each), ℓ, to the double of the tolerable displacement of a magnet unit across the foundation beam.

Suppose we shorten all straight-sections that are not lengthened and keep the average machine radius constant in the sense of making

$$\frac{(R + a) + (R + b)}{2} = 100 \text{ m} \tag{4}$$

Peak excursions of the new form from the old are then

$$\pm \frac{b - a}{2} \tag{5}$$

The ratio of this to ℓ is given in the last column of Table I.

Suppose that radial displacements of magnet units by 0.2 m would be tolerable (response of the foundation beam to the added tilting moments obviously needs to be estimated). This gives us, as function of n, the upper limits on ℓ determined by this criterion. Direct scaling is valid if another displacement limit is considered. See Table II, second column, for this ℓ_{max}.

Table II

n	ℓ_{max} ($\pm$ 0.2 m shifts radially) (metres)	$-\Delta\ell$	θ
2	0.8		90°
3	1.38		60°
4	1.93	0.080	45°
5	2.46	0.129	36°
6	2.98	0.19	30°
7	3.51	0.26	25.71°
8	4.02		22.5°
9	4.55		20°
10	5.05	0.56	18°
12	6.08		15°
15	7.63		12°
20	10.26	2.56	9°

To realise these extra lengths other straight-sections must be shortened. The amount can be estimated to good approximation if n is not too small by assuming the total circumference unchanged, giving the formula : average reduction of straight-sections not lengthened

$$-\Delta\ell = +\frac{n\,\ell_{max}}{100 - n} \qquad (6)$$

Tabulated in third column Table II.

It is clear that for high n this is a more severe limit on the available ℓ than the usable-width of the foundation.

Supposing some practical limit on the average $-\Delta \ell$ that can be squeezed out of the other straight-sections, it is evident (see (6)) that it should be put into the smallest possible number of lengthened ones, to get the biggest increase of them.

Cases n = 4, 5, 6, 7 or thereabout look the most interesting; but one has some reservations about using 6, since it is so close to Q.

Suppose we want to keep the polygon rather regular, and include ss 1 among those to be lengthened. Possible patterns are listed below. One can take at least $\pm$ 1 on the positions as negligible.

n = 4

1

26 $\pm$ 1 useless except for injection.

51 $\pm$ 1 useless for targets. Kicker for $\sim$ 63 $\pm$ 1 ?

76 $\pm$ 1 useless for targets.

n = 5

1

21 $\pm$ 1 useless for targets.

41 $\pm$ 1 useless for targets. Kicker for 61 $\pm$ 1 ?

61 $\pm$ 1 East area.

81 $\pm$ 1 useless for targets. Kicker for 1 ?

n = 6

1

17 or 18 useless except perhaps for ejection to storage rings.

34 or 35 useless for targets.

51 $\pm$ 1 useless for targets. Kicker for $\sim$63 $\pm$ 1 ?

67 or 68 useless for targets.

84 or 85 useless for targets.

n = 7

1

15 or 16 useless except perhaps for ejection to storage rings.

29 or 30

43 or 44

58 or 59 East area, but too far upstream except for ejection or very small angle beams

72 or 73

86 or 87

There seem to be two cases of outstanding interest :

1. n = 5 Useful changes for targetry :

ss 1 lengthened.

ss 60 or 61 or 62 lengthened (or the available length distributed among them).

Extra length available in each region :

2.46 m, if limited by ± 20 cm radial displacements, and if 13 cm average can be found in the other 95 straight-sections.

The 13 cm average looks fairly reasonable : in typical straight-sections, containing lenses, pick-up stations, or cavities, it is about equal to the available clearance if one assumes that all problems of flanges, bellows, vacuum valves, and the possibility of assembly, can be solved.

2. n = 7 Useful changes for targetry :

ss 1 lengthened.

ss 58 or 59 lengthened in the East area.

We can probably include 60 in the East area possibilities if desired (for example, by basing the pattern on ss 2 even though it may be 1 that we lengthen in the South), and still have a near-enough regular pattern.

Extra length available in each area :

3.51 m if limited by $\pm$ 20 cm radial displacements, and if <u>26</u> cm average can be found in the other 93 straight sections.

<u>But</u> 1.76 m if limited to 13 cm average in the others, because 26 cm average probably means suppressing most present-type pick-up stations, or something equally drastic.

Effects of such changes on the CPS performance are difficult to estimate; as soon as we have available a design of injection quadrupole that can be put in almost any straight-section, it would be possible (but quite a lot of work) to make some simulated tests with 5-fold or 7-fold symmetrical n-type perturbations.

The above types of machine distortion all involve moving every magnet unit, changing every set of bus-bars, and changing the vacuum chamber arrangements in every straight-section. The azimuthal magnet shifts range up to values that will involve quite a lot of work on foundations and connections.

B. <u>The Local Solution</u>

If we put the emphasis on the two lengthened straight-sections that are useful in the South and East, and disregard for the moment the possible uses of the others, we should consider what happens if we abandon the n-fold symmetry or near-symmetry that we have so far imposed, and try rather to make only the necessary minimum of changes to fit in the wanted lengthened straight-sections. There are two possible approaches :

1. One straight section is increased by ℓ (or ℓ is distributed over a very small number of adjacent straight-sections). This length is found by a relatively small decrease of all the straight-sections in a certain arc that extends $\pm\ \theta$ on either side of the lengthened straight-section, and the rest of the machine is undisturbed.

One can construct a vector diagram for the straight-section length changes (treated as vectors they must total zero, so that the new arrangement fits the gap in the unperturbed rest of the machine) and one finds that for the same ℓ and θ the radial shift required is just double that of equ. (5) (not surprising, because it now cannot be shared between inward and outward displacements), and the shortening $-\Delta L$ is approximately the same.

For example, if $\theta = 36^{\circ}$ (ten magnet units, similar to the n = 5 case) available ℓ = 1.23 m if limited by - 20 cm radial shift.

6.5 cm average to be found on neighbouring $\sim$ 20 straight sections.

$\sim$ 20 magnets moved.

Or $\theta \approx 26^{\circ}$ ($\sim$ 7 magnet units, similar to n = 7 case) available ℓ = 1.76 m if limited by - 20 cm radial shift.

13 cm average to be found on neighbouring $\sim$ 14 straight sections.

$\sim$ 14 magnets moved.

There seems to be every incentive to work with a small θ, trying to find the length by big changes in a small number of shortened straight-sections; for at given ℓ this reduces the radial shift and the amount of physical work. In the limit this results in the approach no 2) :

2. The desired extra length is obtained even more locally, by shortening (typically) two to three immediately neighbouring straight sections by amounts in the half to one metre region.

Such proposals have to be considered entirely on an individual basis, taking into consideration the local hardware requirements. They are outside our terms of reference.

C. <u>The irregular arrangement</u>

This is the case where we lengthen two or three straight sections chosen entirely for utility, without regard to any regular pattern; we consider ourselves free to lengthen one or two others, if this helps to keep the overall shape of the machine convenient; and we move whatever magnets and shorten whatever straight sections may be necessary to acheive this. It is the most difficult case to consider in any systematic fashion.

Suppose we lengthen a straight section by some useful amount ℓ, say a metre or more. This length must be recovered by shortening straight sections spread over some angle θ on either side of it. For if we do not recover any of this length within the 90° on either side, we find a diameter increased by ℓ, and so exceed the tolerable radial displacements on the foundation beam. (If we recover the ℓ uniformily over $\pm 90^{\circ}$, from the first row of Table I one sees that even then $\ell/4$ radial displacements are needed at the ends of this diameter.) So one can suppose that the length must be recovered over some region like $\pm 45^{\circ}$ or less in any case.

The relative arrangement of the units and straight sections within this region containing the lengthened straight section and the $\pm\,\theta$ on either side of it in which the length is recovered will therefore be just the same as in the corresponding B, Local Solution, case. So the only thing that one can hope to gain by freedom to play also with the arrangement of the rest of the machine, is a reduction of the radial displacement, which would otherwise have a peak value of $-\ell\,(\text{cosec}\,\theta - \cot\theta)/2$.

A convenient way of doing this is a small increase in the lengths of the two straight sections at $\pm 90^{\circ}$ from the one lengthened. Very roughly this enables us to halve the peak radial excursion, and brings one back to the situation where Table II gives the quantities needed to find what is possible for any θ.

In such a system 50 magnet units have to be moved to make a lengthened straight section, but it is of some value that in the regions between the $\pm\,\theta$ points and the $\pm 90^{\circ}$ points the straight section lengths do not change, and here the old vacuum plumbing and bus bars remain usable.

Conclusion

My personal impression is that the $n = 5$ and $n = 7$ regular-pattern solutions are not worth an extensive study unless it appears that they fit rather well some overall plan of long term exploitation, say one in which more than half of the lengthened straight sections can be put to some really profitable use.

The case where 2 or 3 useful straight sections are lengthened by something in the 3 m region, by method C, with θ of the order of 30°, is a major undertaking which must just be weighed aginst the usefulness of such straight sections, and against the possibilities of the Local Solution.

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A P P E N D I X-III

FURTHER THOUGHTS ON PRIMARY AND SECONDARY BEAMS FROM VARIOUS STRAIGHT SECTIONS

Efficient use of primary and secondary beams is facilitated, if the two do not emerge from the same straight section. (More beams from the same internal target, easier sharing between internal and external targets, less induced radio-activity in ejection magnets). For both types of beam a mid-D straight section is advantageous compared to a mid-F s.s. [1][2]

It looks therefore interesting to create 2 medium long mid-D s.s. (such a length would probably allow to house a septum magnet with a rather thin effective septum width making for efficiencies well above 90°/o) by reducing to a minimum a long mid-F s.s. (no. 1, 61 etc.).

There are then 2 cases, either

i) to eject from the first m.s.s, and to provide secondary beams from the second one or

ii) vice-versa, case (ii) has the advantage that the ejected beam and secondary beams will probably be better separated physically, as the latter have a tendency to come out at somewhat larger angles than the former. Also, any targets and their supports do not get into the way of the ejected beam. (A conceivable pratical case would be e.g. to produce secondary beams from lengthened s.s. 100 and to eject from lengthened s.s. 2)

If one ejects first (case ii) one advantage is that the ejection magnet does not get irradiated by the secondary beams. However, the following problem arises. There is little space (only between coil covers) to place a lens in the subsequent straight section, to refocus the beam horizontally . At that point a typical beam may have a total width of 25 to 50mm and a divergence of 2 to 5 mrad. At the next s.s. it will have become 50 to 100mm wide, that is uncomfortably large for the apertures invisaged for ejected beam transport magnets. In this situation it seems advantageous to use a focussing septum magnet, as proposed earlier to ease the aberration problem.[3] Preliminary results show that a parallel beam in the horizontal plane may be obtained after the first magnet unit using reasonable gradients.

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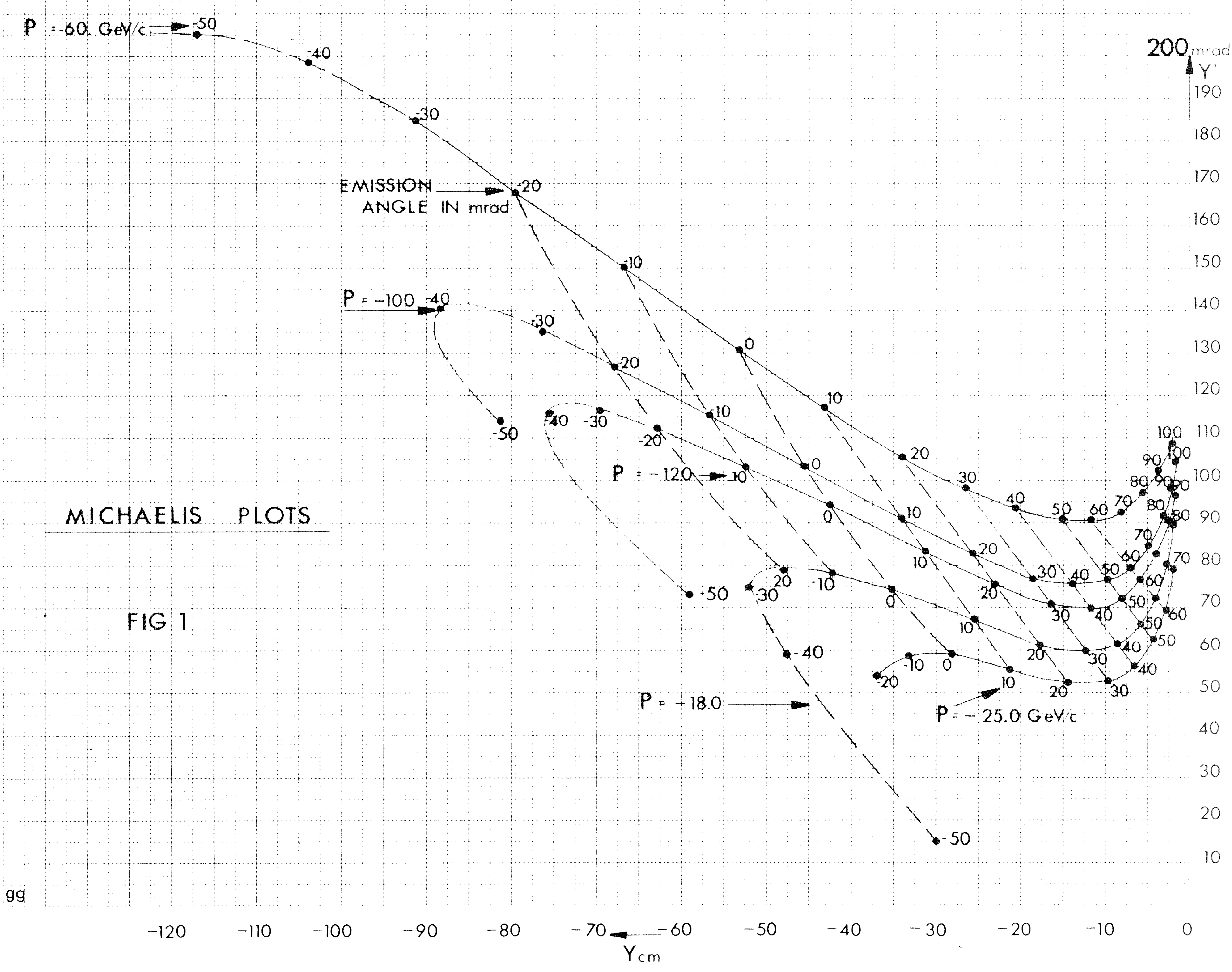
1) J. Geibel - MPS/EP/14
2) K.H. Reich MPS/Int/DL 63-8
3) MPS/Int/DL 62-25

NOMINAL PROTON MOMENTUM = 24.9 GeV/c
STANDARD TARGET POSITION
LONG DEFOCUSSING STRAIGHT SECTION
(2.9432 m. BETWEEN IRON FACES)



MICHAELIS PLOTS

FIG 1

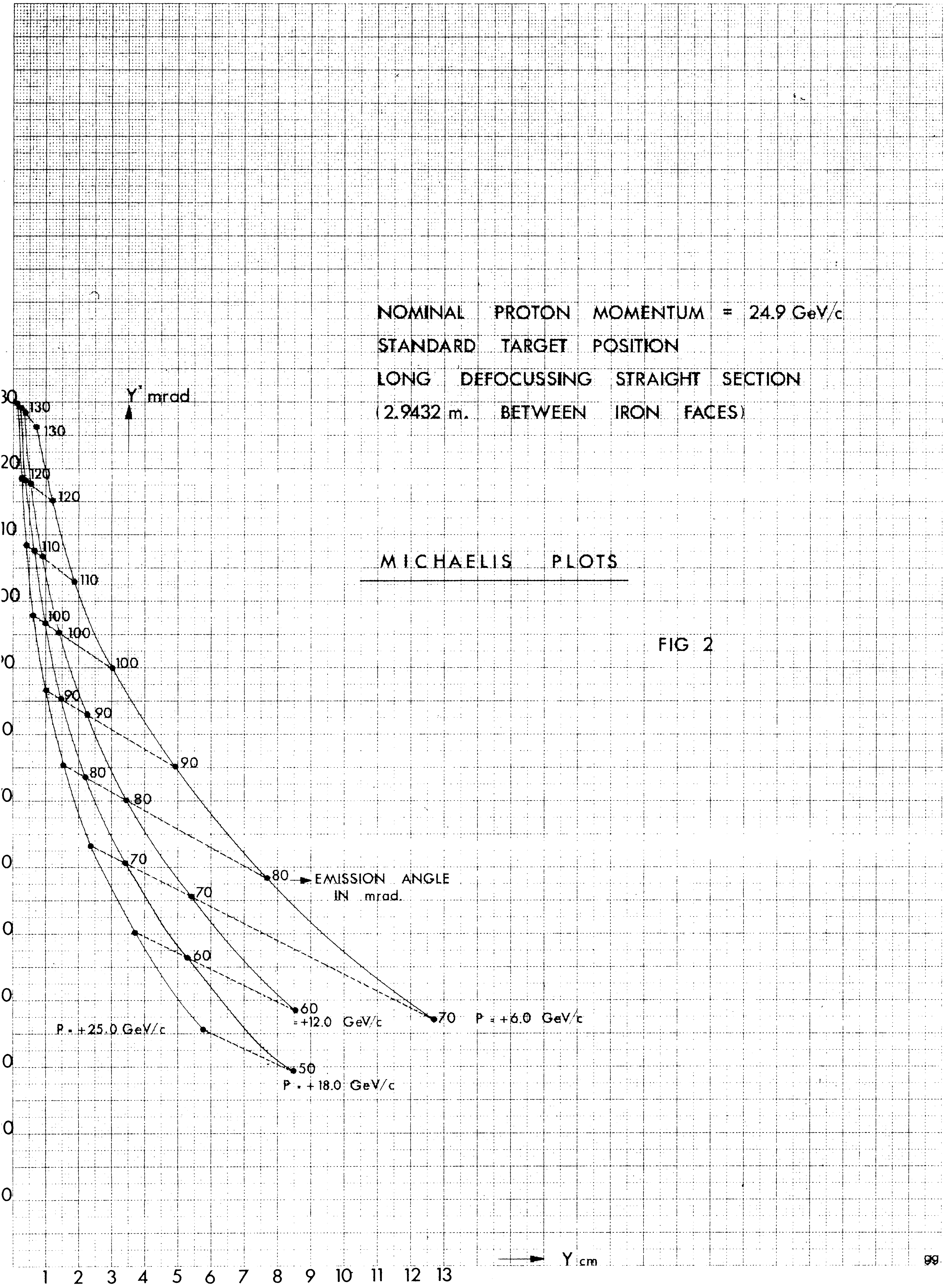

NOMINAL PROTON MOMENTUM = 24.9 GeV/c
STANDARD TARGET POSITION
LONG DEFOCUSSING STRAIGHT SECTION
(2.9432 m. BETWEEN IRON FACES)
MICHAELIS PLOTS
Y' mrad
Y cm
EMISSION ANGLE IN mrad.
P = +25.0 GeV/c
P = +18.0 GeV/c
= +12.0 GeV/c
P = +6.0 GeV/c
1 2 3 4 5 6 7 8 9 10 11 12 13

FIG 2