EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/ISRC/69-22
8 April 1969

INTERSECTING STORAGE RINGS COMMITTEE

MEMORANDUM

To : ISRC

From : A.B. Clegg, C. Daum, F. Erné, A.D. Kanaris, D. Locke, P.G. Murphy, J.C. Sens and F. Udo (CERN/Holland-Lancaster/Manchester Collaboration)

Re : Is the split-field system (Steinberger) suitable for a particle production experiment?

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Re : Is the split-field system (Steinberger) suitable for a particle production experiment?

A particle production experiment has been proposed 1) in which septum magnets are used to extract particles emitted at angles $\gtrsim$ 15 mr from the intersecting beam volumes. On the other hand a large magnet system is under discussion for use in more specific experiments where very small angles as well as large solid angles are important. The question can thus be raised whether a particle production experiment cannot also be done with one of the suggested large magnet systems. In the following this question will be considered for the split-field system (SFS), proposed by Steinberger.

For the comparison it will be assumed that in SFS the three fields which are traversed by each beam are 1.1 T in magnitude and 2.8, 5.6 and 2.8 meters in length respectively. It is furthermore assumed that a tube of elliptical cross-section with semiaxes R_H = 7.5 cm and R_V = 3.5 cm around the primary beam is not accessible for measurements; this space is taken up by a special (smaller than standard) vacuum pipe, spark chamber edges etc.

1) Minimum angles

The thermodynamical model predicts the rate of each kind of secondary particle to be a more or less steeply dropping function of angle, see fig. 1. Integrated over all momenta and summed over all kinds of secondaries one obtains that ~ 40% of all particles are produced in the angular interval between 0 and 20 mr. This is one, although not the only reason why it is important to reach the smallest possible angles.

In order to determine the minimum angle in SFS it is assumed that a precision of, say, 2% in momentum is required and that the sagittae(s) can be determined to 1 mm. Then

$$\frac{\Delta p}{p} = \frac{0.001}{S} = 0.02 \ , \ S = 0.05 \text{ m.} \tag{1}$$

S is related to the length of the track ℓ_s in the field by

$$S = \frac{\ell_s^2}{8\rho} = \frac{3}{80}\frac{B\,\ell_s^2}{p} \qquad (\rho = \text{radius of curvature}) \tag{2}$$

Hence

$$\ell_s = 1.1\sqrt{p} \quad \text{m} \quad \text{with } p \text{ in GeV/c.} \tag{3}$$

The track must thus have left the tube a distance $\geq \ell_s$ from the exit end of the magnet. Now for a secondary of momentum p, emitted at angle ϑ, the deflection in the horizontal place at a distance ℓ from the entrance end of the 6 m magnet (field B, length L_1) is given by:

$$d_{1H} = \ell\,\vartheta_H + \frac{0.15\,B_1\ell^2}{p} \quad \text{if } \ell < L_1 \tag{4}$$

where θ_H is the projection of θ on the horizontal place. For $L_1 < \ell < L_2$ i.e. in the compensator (field B_2, length L_2) the horizontal deflection is

$$d_{2H} = \ell\,\theta_H + \frac{0.15}{p}\{B_2\,\ell^2 + (B_2 - B_1)\,L_1^2 - 2(B_2 - B_1)\,L_1\,\ell\} \tag{5}$$

In the vertical place the deflection is:

$$d_V = \ell\,\vartheta_V, \tag{6}$$

where ϑ_V is the projection of ϑ on the vertical plane. Furthermore

$$\theta^2 = \vartheta_H^2 + \nu_V^2 \tag{7}$$

The minimum angle now follows from the condition that at a distance

$$l = L_1 + L_2 - l_s \tag{8}$$

from the intersection the particle traverses the wall of the tube (semiaxes R_H and R_V). Thus:

$$\left(\frac{d_{1,2H} - d^{B}_{1,2H}}{R_H}\right)^2 + \left(\frac{d_V}{R_V}\right)^2$$

where $d^{B}_{1,2H}$ is the horizontal deflection of the primary beam, obtained from eq's (4) or (5) by setting $\theta = 0$ and p/p_{beam}. The minimum angle θ_{min} is then obtained by differentiation of eq. (9), considered as a factor of θ and, say φ_H.

The results for positive particles are indicated in Fig. 2 for an effective vacuum tube of semiaxes 7.5 and 2.5 cm (i.e. the standard ISR tube) and also for an enlarged tube, with semiaxes 8.5 and 3.5 cm. At momenta above $\sim$ 20 GeV/c the minimum angle is determined by the vertical dimension of the tube. At momenta $\lesssim$ 17 GeV/c the bending by the field is sufficiently strong to reach the minimum angle in the horizontal plane. Between $\sim$ 20 and $\sim$ 17 GeV/c the minimum angle lies in a "skew" plane. Fig. 2 shows that for 25 GeV/c the minimum angle is 8.5 or 12 mr depending on assumptions about the tube. We take 10 mr as a working figure.

Thus far it has been assumed that the momentum measurement is done inside the magnets. One may, however, ask a different question, namely which particles will emerge from SFS and will then be available for identification and momentum measurements outside.

Fig. 3 shows which trajectories just clear the next ISR element. They have been calculated from eq's (4) and (5). Only one beam is indicated. The scale is enlarged in the direction of the deflections. The shaded area indicates the projection of the effective vacuum pipe on the horizontal plane. Track B indicates the minimum angle a 25 GeV/c particle produced in the horizontal plane must have in order to be measured with a precision of 2% in momentum. Track C indicates the maximum momentum of a 0 mr particle that will clear the next ISR element. Track D indicates the minimum angle for a 25 GeV/c particle with which the next ISR element can be cleared.

Negatively charged particles can be extracted from the magnets in two ways: 1) reversing all polarities; the point of intersection is then displaced from one to the other side of the equilibrium orbit. The vacuum pipe must be replaced by another one when switching from + to - particles. Both + and - particles will emerge at the same side of the beam. 2) leaving the polarities and the vacuum pipe unchanged but having two sets of detectors outside the magnets, one at either side of the beam. In either way of extraction, all - particles will emerge from the magnets, including 0 mr, 25 GeV/c.

2) Identification of secundaries

According to the thermodynamical model, we have the following fractional contributions to the rate at a typical small angle, e.g. 25 mr:

	20 GeV/c	15 GeV/c	10 GeV/c	5 GeV/c
$\frac{\text{+ part.}}{\text{all part.}}$	99.8%	97%	87.5%	66%
$\frac{\pi^+ + K^+}{\text{all +}}$	1%	14.5%	51%	92%

This illustrates that if a particle is emitted at small angles and has $\sim$ 20 GeV/c or more, it has a 99% change of being a proton, even if its charge is not identified. It will nevertheless be of interest to determine the fraction of high momenta $\pi^+ + K^+$, since it provides an upper limit on the production of isobars; this fraction is in fact one of the most important results one can expect from a yield experiment. At lower momenta the fraction of protons is rapidly decreasing and identification is thus unavoidable.

It is at present not clear how to identify particles in SFS. On the other hand, with septum magnets all particles with $\geq$ 15 mr and $\leq$ 25 GeV/c are deflected enough to permit the use of Cherenkov counters for their identification.

3) Minimum t

Of more significance than the minimum angle is the minimum momentum transfer squared $t((\text{GeV/c})^2)$ which can be reached in the two systems. For 50 GeV CM energy, $t_{min} \approx 0.14$ $(\text{GeV/c})^2$ for the septum system (θ_{min} = 15 mr), while for SFS $t_{min} = 0.063$ $(\text{GeV/c})^2$ (θ_{min} = 10 mr). CM energies below 50 GeV can be obtained with a variety of beam momenta ranging from "equal momenta" to "maximally unequal momenta" in the rings. As pointed out in ref. 1, their setting differ in t_{min}, the "unequal" case being the more favourable if the secondary is detected opposite the beam of lowest moment.

In the septum system there is no difficulty in running with unequal momenta, since there is no interference with the circulating beams. In SFS, on the other hand, running with unequal momenta presents problems: since the 6 m magnet in each beam is also in part traversed by the other beam, one canrot independently compensate a change in momentum in one beam by a change in field in order to keep bending angles and point of intersection the same. As a result the point of intersection moves along the machine azimuth when the momentum of one beam is changed. Using again eqs. (4) and (5) one obtains a shifts of ~ 75 cm for a change from 25 to 10 GeV/c. The trajectories of the two beams are shown in fig. 4; in the construction the crossing angle has been ignored for simplicity. It is seen that a substantial displacement of the vacuumpipe and the wire chambers over the shole length of the magnets is required if unequal momenta are to be accomodated in the system.

The usefulness of running with unequal momenta is illustrated in the table below (see also Fig. 1 of ref. 1).

CM EMERGY	BEAM MOMENTA	t_{min} $(GeV/c)^2$	
GeV	GeV/c	SEPTA	SFS
50	25/25	0.14	0.063
32	16/16	--	0.026
32	10/25	0.023	--

Thus, with SFS, t_{min} will be lower than with septa by a factor ranging from 1 to ~ 2.5. Unless the pipe and detectors in SFS can be made to move, t_{min} is about the same in both systems at 32 GeV CM energy.

4) Monitor

The interaction volume consists of a parallelopiped with sides 60 cm long, crossing at 15°, and height ~ 14 mm. Inside this volume there is a nonuniform distribution of points of interaction, to be determined by experiment. As shown in ref. 1 this is done by means of two monitors, placed at 90° to the beams in the horizontal and vertical planes. Since an estimated 98.6% of all charged secondaries at 90° produce multiple scattering of $\gtrsim$10 mr in the walls of the vacuumpipe and are therefore not useful in locating the points of interaction liquid or glass Cherenkov counters, or time of flight over several meters are incorporated in the monitors, in order to cut out particles with $\beta \lesssim 0.75$. It seems difficult to accomodate such a monitor in SFS, in particular in the vertical direction. For the monitor in the horizontal plane there is the added complication that in the field of SFS the trajectories are bent and therefore do no longer present a simple image of the interaction volume; displacements of up to 1 meter occur at the exit of the magnet.

It is probably not impossible to find solutions for these problems; on the other hand, with the septa they simply do not arise.

5) Acceptance

Fig. 5 (left side) shows the three regions I, II, II in the distributions of angle and momentum in SFS. In II the secondaries do not clear the next ISR element and can therefore not be identified in a simple way; the acceptance is, however, large. In III the particles clear the next ISR element and can thus be identified in a Cherenkov counter outside; the acceptance is again large, e.g. for a 50 cm diameter counter at 10 m about 2 msr, i.e. a factor 20 higher than the septum system would provide*). The counters must be movable to intercept the tracks (see e.g. tracks C, D and E in Fig. 3).

CONCLUSIONS

The two principal elements of a comparison between SFS and septa are minimum angles and particle identification. In either system a large part of the high momenta-small angle region, of particular relevance to isobar production, remains inaccessible. This being granted, the system of septa is strongly to be preferred for the following reasons:

1) Minimum angle. With the septa the minimum angle (see Fig. 5) for

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*) In an improved version of the spectrometer in ref. 1 its acceptance has been increased to 0.1 mr.

positive and negative particles, ranges from 15 mr (at 25 GeV/c) to 8 mr (below 15 GeV/c; obtained by moving the septa away from the intersection when measuring low momenta); for SFS the minimum angles for positive particles at high momenta lies between 8 and 12 mr (depending on the exact lay-out of equipment in the magnets) and drops to 0 mr below 15 GeV/c. Hence the difference in θ_{min} at high momenta is small, while at low momenta, where the distributions are much less peaked, it is irrelevant. For negative particles, SFS presents no limitation: all momenta and all angles emerge from the vacuumpipe close enough to the intersect to make an accurate momentum measurement possible on the visible part of the track in the magnet.

2) Particle identification. With the septa, a particle which is detected i.e. the momentum of which is measured, is also identified. With SFS, at 25 GeV/c an angle of $\geq$ 55 mr is required in order that a positive particle emerges from the magnet for identification; this angle drops to 0 mr at $\sim$ 10.5 GeV/c (see Fig. 5). Hence, over a large part of the angular distribution no identification can be made unless Cherenkov counters are placed inside the magnets, which cannot be done without raising the minimum angle for momentum determination. Since isobars produce high momentum pions and kaons at very small angles, against a $\sim$ 99% "background" of protons (in part associated with multipion processes) particle identification at small angles is an <u>essential</u> part in any experiment concerned with "resonances". For negative particles, SFS presents again no limitation since all particles can be extracted from the magnet, for identification outside.

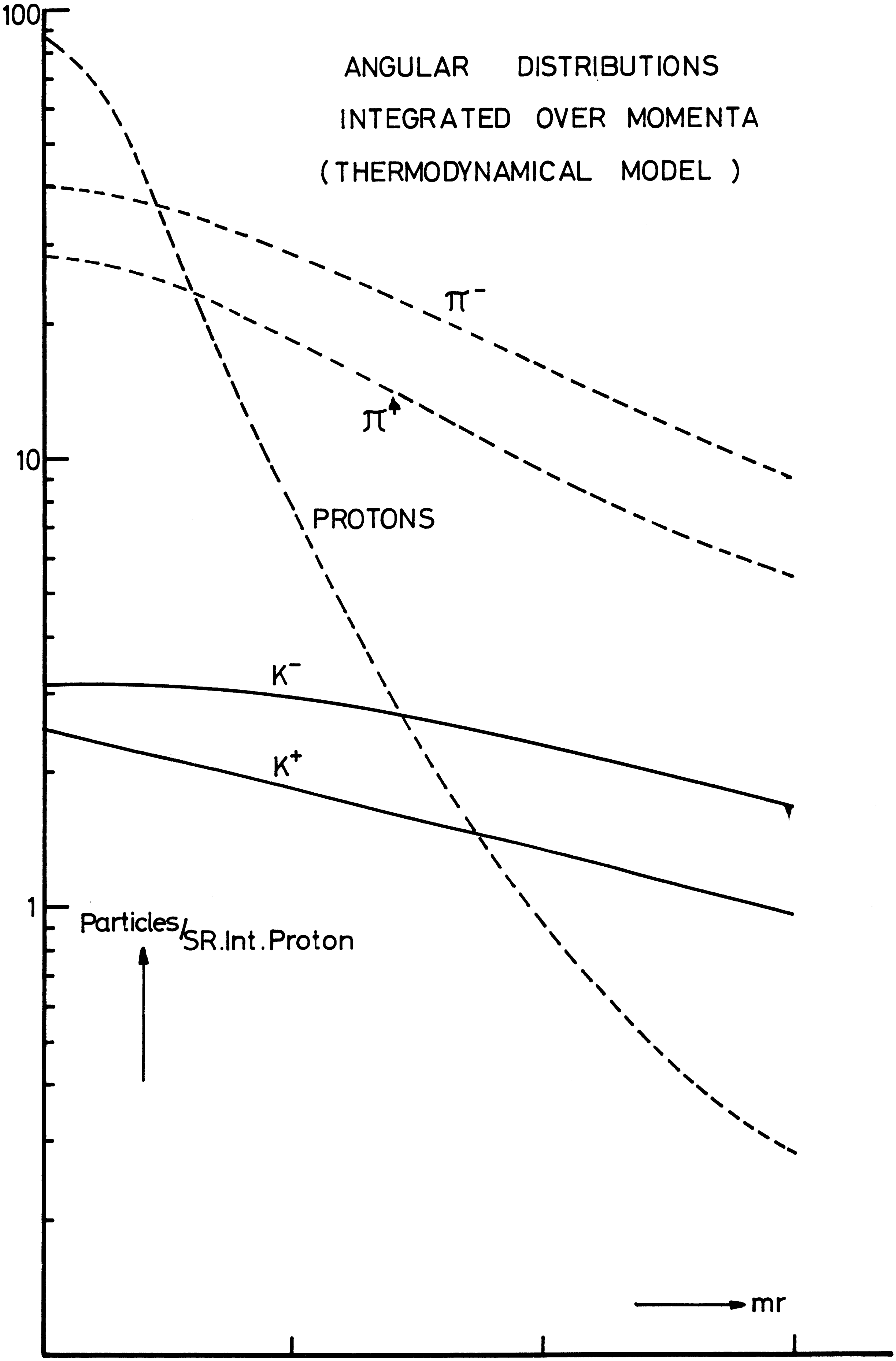
3) Interference with ISR. This is an obvious advantage of septa. The septa can be moved into place gradually, with full control over their eventual effect on the stability of the beams. With SFS, no such "on-off" type of test is possible.

4) Cost of construction and operation. SFS has been estimated to cost 12 x 10^6 Sw frs. Septa cost one to two orders of magnitude less. SFS uses 6 MW septa 600 KW of power.

In conclusion it seems evident that for a survey experiment as proposed in Ref. 1, where simplicity, rapid feed-back, complete particle identification, low cost etc are important, a system of septa has a clear advantage over a large magnet system.

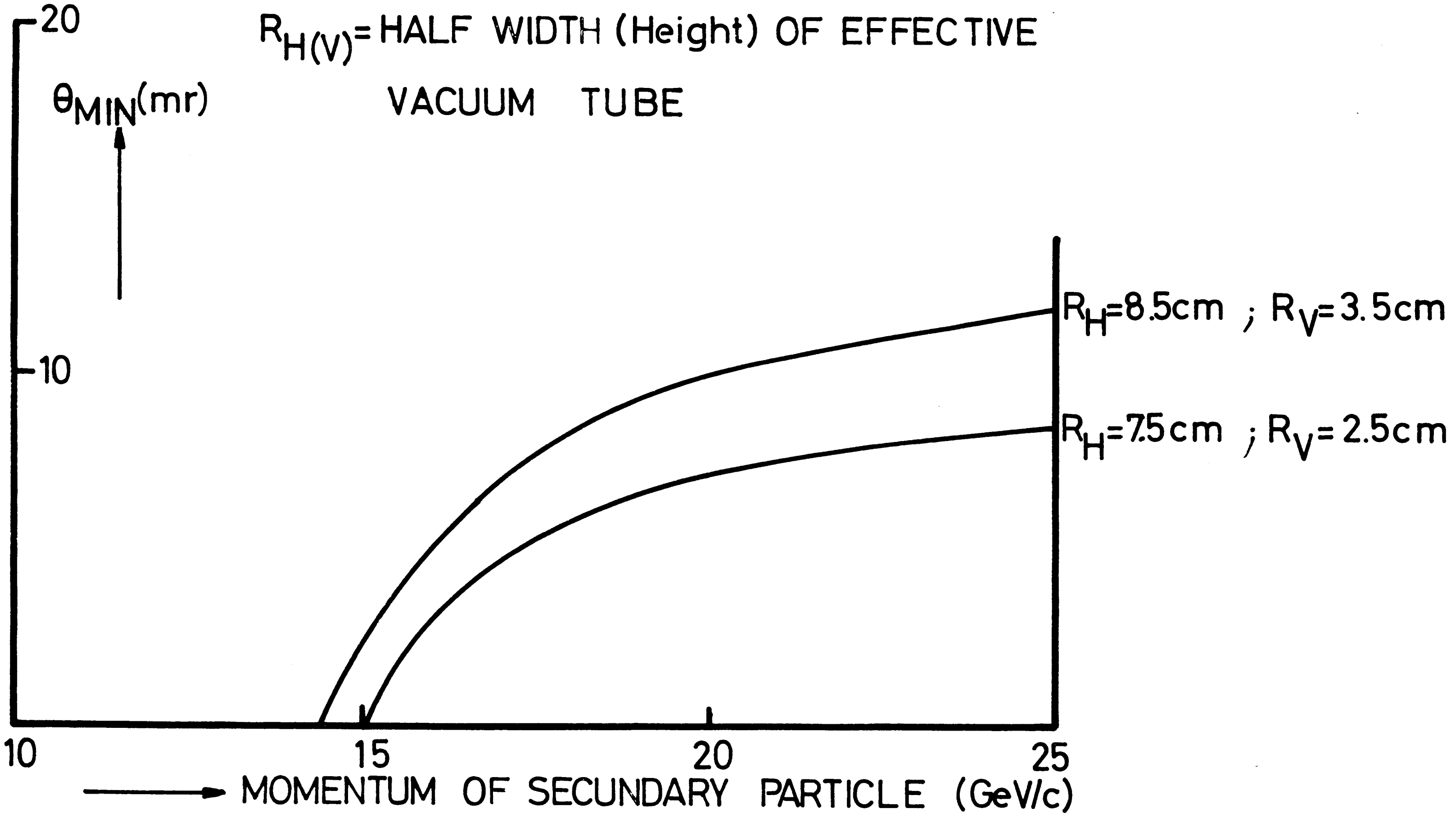
This note has been written for the specific purpose of comparing SFS with septa from the point of view of a particle production experiment; however, some of the difficulties encountered seem to be of a more general nature.

<u>REFERENCE:</u> 1) A.B. Clegg et al., "Measurement of the production of stable particles at the ISR" (CERN/ISRC/69-5).

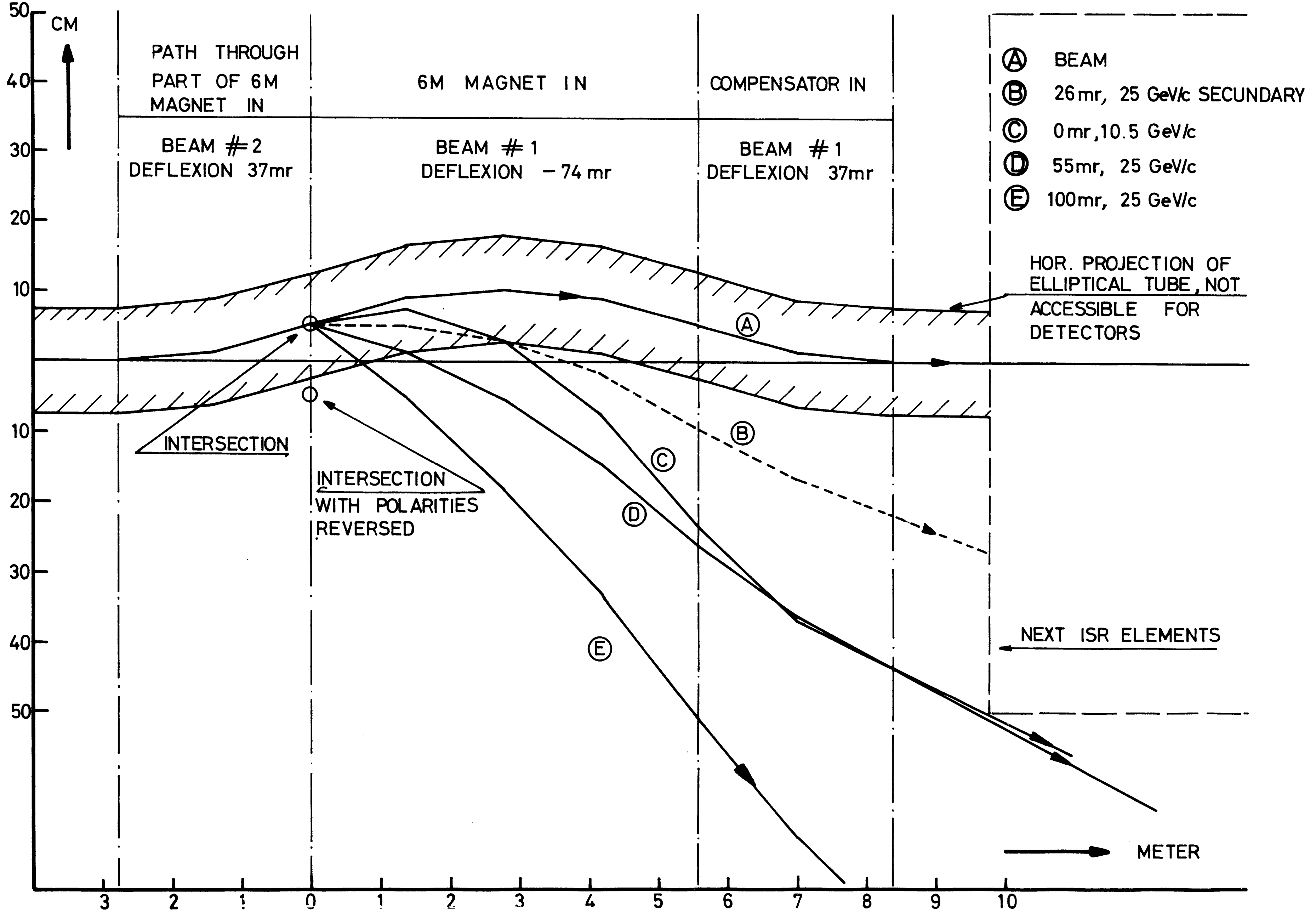


ANGULAR DISTRIBUTIONS
INTEGRATED OVER MOMENTA
(THERMODYNAMICAL MODEL)

MINIMUM DETECTABLE ANGLE OF
PRODUCTION OF POSITIVE SECUNDARY
PARTICLES IN THE SPLIT-FIELD SYSTEM
FOR A PRECISION OF 2% IN MOMENTUM
$R_{H(V)}$= HALF WIDTH (Height) OF EFFECTIVE
VACUUM TUBE

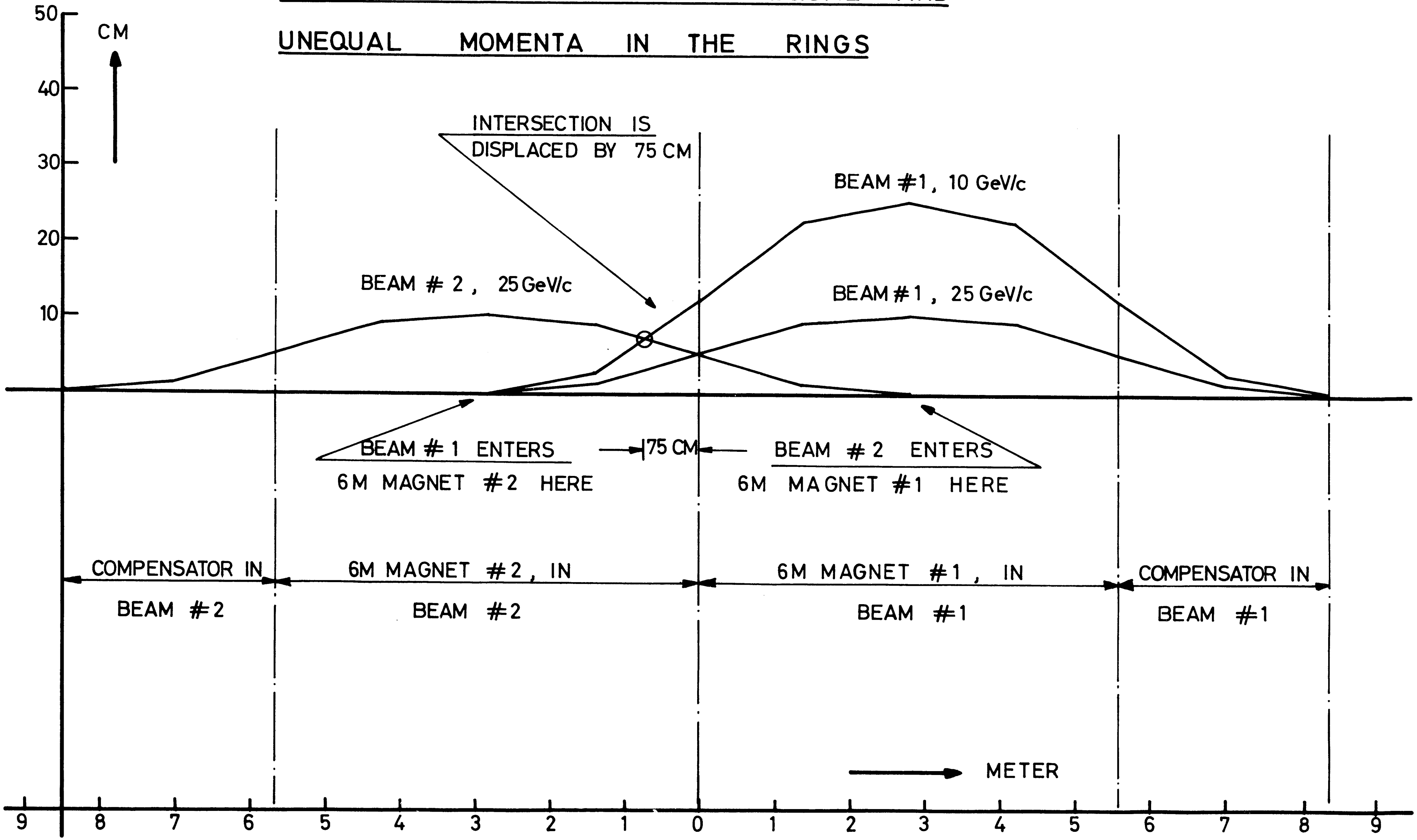


SPLIT - FIELD MAGNET SYSTEM (STEINBERGER) FIELDS 1.1T



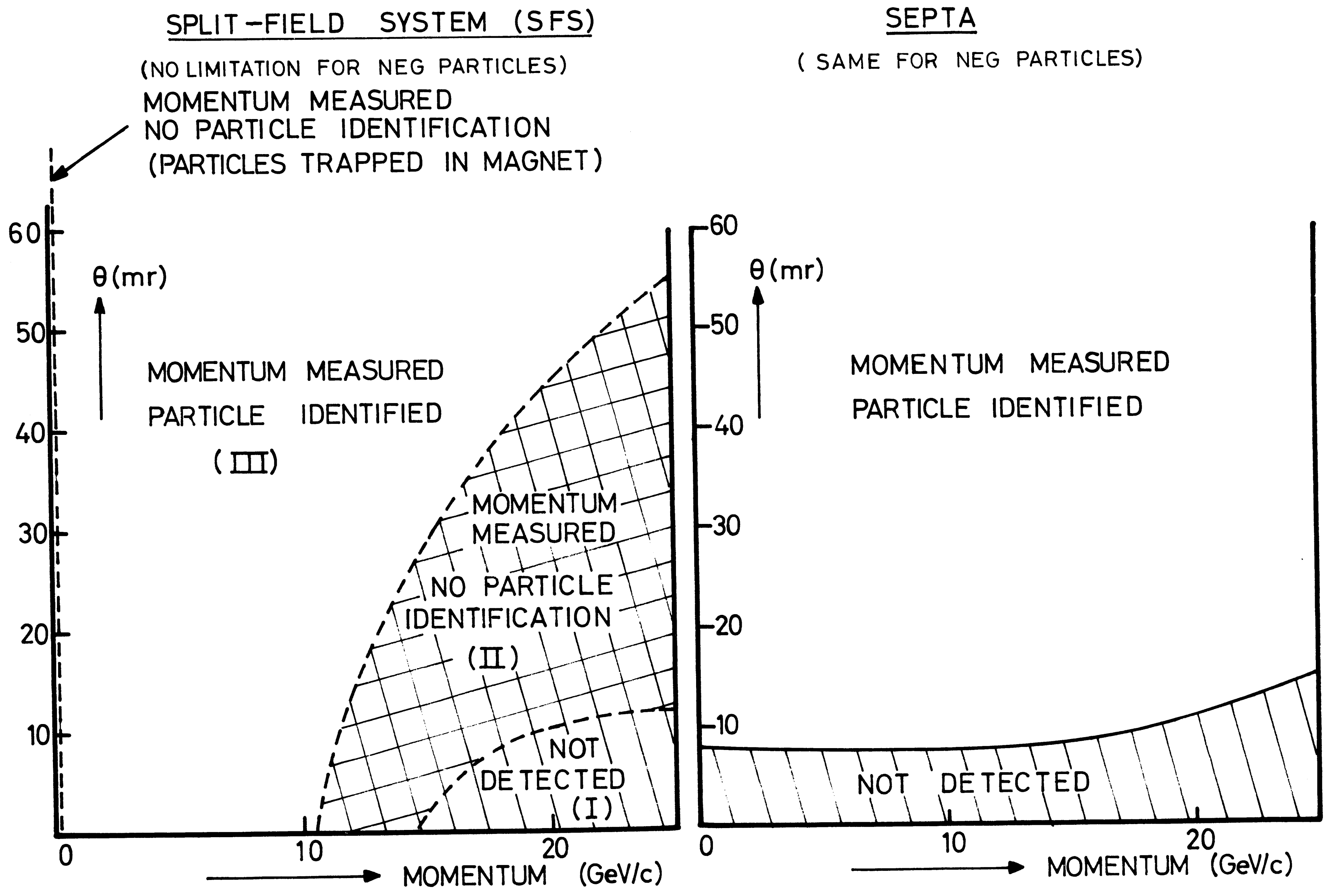
SPLIT-FIELD SYSTEM (STEINBERGER)

POSITION OF INTERSECTION FOR EQUAL AND UNEQUAL MOMENTA IN THE RINGS



COMPARISON SFS ⟷ SEPTA

(FOR POS. PARTICLES)



SPLIT-FIELD SYSTEM (SFS)

SEPTA

(SAME FOR NEG PARTICLES)