Met target irradiated by this scheme was cut into strips and the radioactivity histogram shown in Fig. 7 was obtained. This shows a reasonable spiral pitch and, presumably, efficiency. The next critical experiment will be to energize the septum and see if the results predicted in Fig. 5 can be obtained.

The hardware needed to implement the actual extraction of the beam is being developed. In addition to the requirements described here, this includes beam transport equipment, instrumentation and shielding.

The author wishes to acknowledge the many valuable discussions with E. D. Courant and G. Parzen. Dr. G. Morgan has assisted with computer programming. C. Lasky and E. Forsyth have provided the author with much information about engineering problems associated with this beam. A. Maschke has assisted with the experimental work.

REFERENCES

(1) J. L. Tuck and L. C. Teng: Phys. Rev. *81*, 305 (1951).
(2) C. Bovet, G. R. Lambertson and K. H. Reich: Measurements on Slow Beam Ejection from the CPS, CERN Report 64-25, (1964).
(3) G. K. Green: External Beam - I, Brookhaven Report GKG-6 (1962).
(4) E. D. Courant: Orbit Stability in Particle Accelerators, Proc. Symposia in Applied Mathematics, Vol IX, p. 1 (American Mathematical Society, 1959).
(5) P. A. Sturrock: Nonlinear Effects in Alternating Gradient Synchrotrons, Ann. Phys., *3*, 113 (1958).
(6) R. Hagedorn, M.G.N. Hine and A. Schoch: Nonlinear Orbit Problems in Synchrotrons, CERN Symp. on High Energy Accelerators Genève, 1956, p. 237.
(7) E. D. Courant: Nonliearities in the AG Synchrotron, ibid., p. 254.
(8) A. A. Kolomenski: On the Nonlinear Theory of Betatron Oscillations, ibid., p. 265.
(9) E. D. Courant: Computations of AGS Orbits with 704 Computer, Brookhaven Report EDC-36, (1960).

SLOW AND FAST BEAM EJECTION FROM A SHORT STRAIGHT SECTION OF THE CERN PROTON SYNCHROTRON

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(Presented by H. G. Hereward)

1. INTRODUCTION

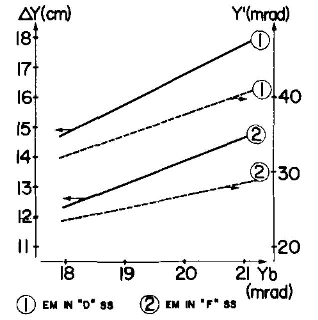
Slow and fast ejection from straight section (s. s.) 58 of the CERN PS was achieved at the end of July 1965. Resonant slow ejection (1) (2) used machine quadrupole 55, sextupoles 5, 15, 35, 45, 75, 95, (3) a 3-4 cm amplitude orbit deformation and a septum-type ejection magnet (EM) placed in s. s. 58 outside the GPS aperture. Fast ejection with the same magnet was achieved by means of the fast kicker in s. s. 97 described previously (4) (5), and a similar orbit deformation of twice the amplitude.

While based on the same principles as ejection from s.s. 1 (1), (2), (4), ejection from s.s. 58 is different in that a unique stationary ejection magnet is used, in a (short) s.s. not employed for internal targenting. This should increase the flexibility of beam sharing between external and internal targets (changeover time < 50 ms) and minimize the mutual interference of the two types of targeting as well as reduce the maintenance.

2. CHOICE OF STRAIGHT SECTION

Assuming that short straight sections could be used for ejection, the choice was between a mid-D and a mid-F one. An EM placed directly outside the required full machine aperture per-

Fig. 1 - External beam coordinates with ejection magnet (EM) in a short mid-D straight section (curves 1, $y_0 = 65$ mm) and a short mid-F s. s. (curves 2, $y_0 = 86$ mm).



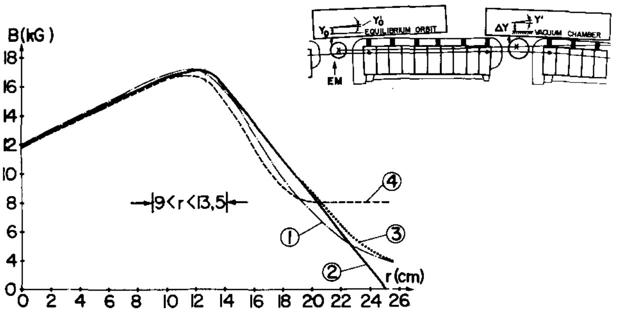


Fig. 2 - Magnetic flux density, B, as a function of distance from the central line, r, in a radially focusing CPS magnet unit. 1 normal unit, 2 unit with hyperbolic shims and neutral pole, 3 hyperbolic shims but no neutral pole, 4 unit with straight, parallel shims.

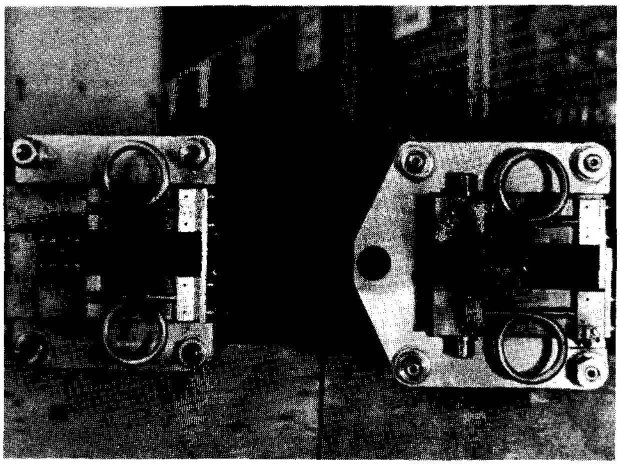


Fig. 3 - The two sections of the ejection magnet (designed for thin septum and high fields)

	Left	Right
Main magnetic field (kG)	10	20
Mean stray field outside septum (G)	6	50
Yoke length (mm)	700	520
Air gap (mm)	19×39	19×30
Septum thickness (mm)	3	6.1
Pulse length at full current (ms)	200	
Duty cycle	1:10	

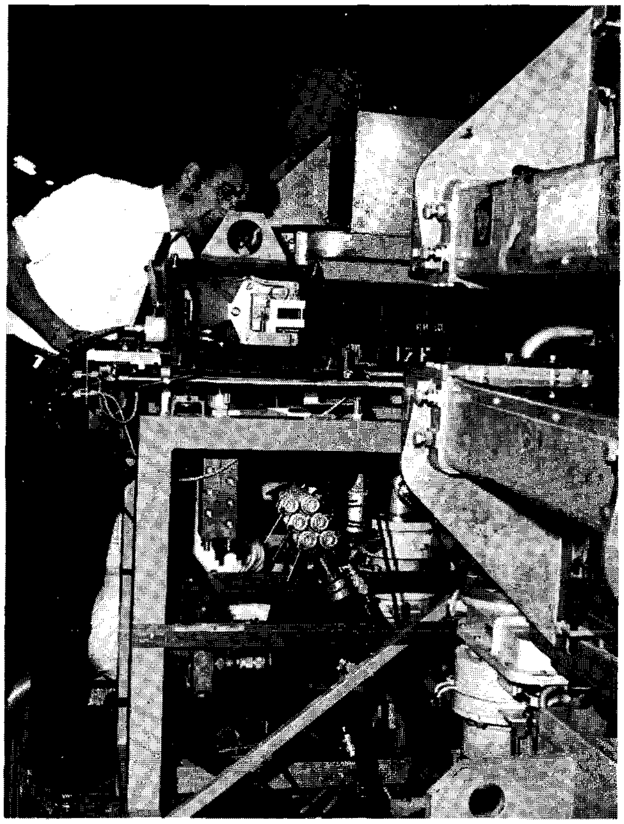


Fig. 4 - Ejection magnet on its support mounted in the CPS (« out » position, vacuum tank cover removed).

mits one to start an external beam at $y_0 = 65$ mm from the equilibrium orbit in a mid-D straight section and at $y_0 = 86$ mm in a mid-F s. s. Deflection by various angles y'_0 in EM leads in the subsequent straight section to the beam coordinates shown in Fig. 1. Here Δy is the distance, in the middle of this straight section, from the outside wall of a minimum-width machine vacuum chamber (taking into account the wiggle factor) to the external beam axis. y' is the angle between this axis and the equilibrium orbit in the same straight section. Δy is the relevant quantity if one needs to place beam transport elements in this straight section, y' for placing such elements in the subsequent straight section (2 downstream from ejection magnet). It turns out that the same Δy can be obtained with 15% less deflection by ejecting from a mid-D type s. s. and the same y' with ~ 22% less deflection.

The merits of a mid-D s.s. were found to be even greater after studying the aberrations in the CPS magnet field (6) (7) (8). In the absence of a focusing ejection magnet reduction of these aberrations required magnetic shimming. Using shims of both hyperbolic and straight pole design (9), the field of an F-type magnet unit could be improved as shown in Fig. 2, except over a radial region ($9.0 < r < 13.5$ cm) which can be avoided when ejecting from a mid-D s.s. The desire to employ the existing fast kicker (maximum beam displacement in s.s. 57) and the

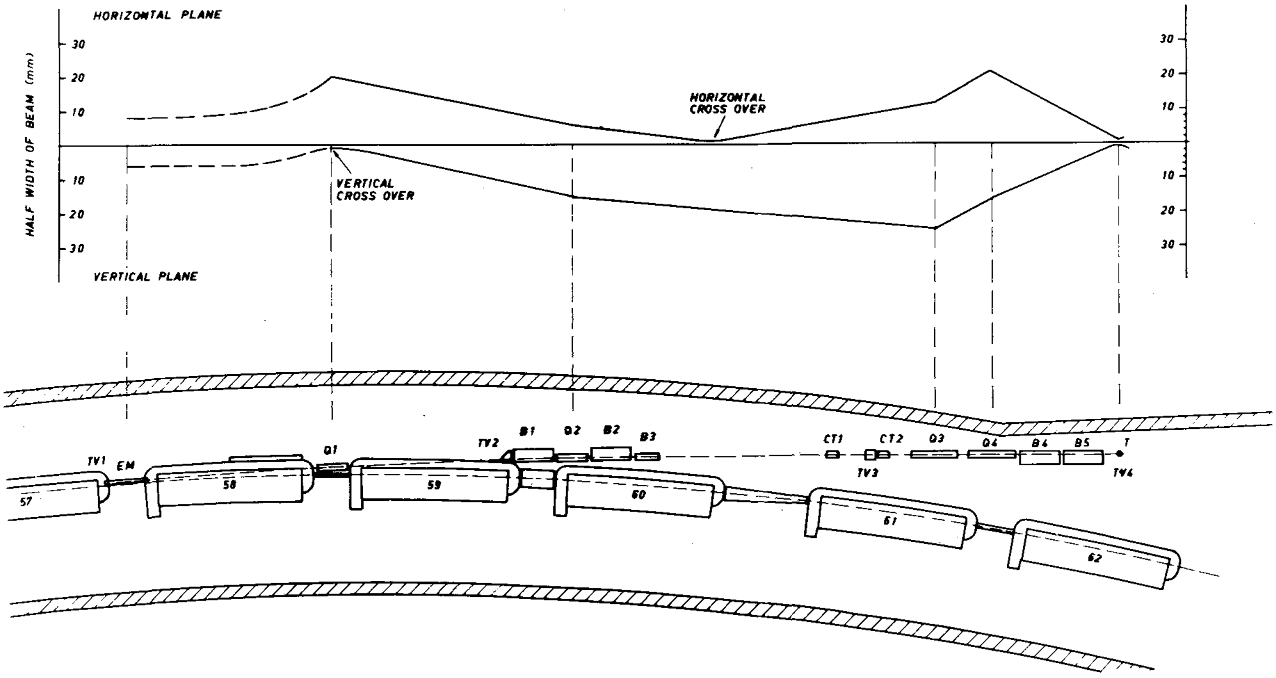


Fig. 5 - External beam.

Botton:	Beam layout
EM	Ejection magnet
Q1 - Q4	Slim d.c. powered quadrupoles
B1 - B5	Bending magnets
TV1 - TV4	Closed circuit television stations for beam observation
CT1, 2	Beam current transformers
T	Target
Top:	Beam optics (schematic)

Note that there is a difference of a factor 100 between the transverse and longitudinal scales.

position of the East Experimental Hall (10) thus led to the choice of s.s. 58. The nominal trajectory itself was mainly determined by the condition of avoiding the undesirable region shown in Fig. 2 with as little deflection as possible, which could be achieved with the septum positioned at 59 $< r <$ 62 mm from the equilibrium orbit and ejection at 19 mrad.

3. ORBIT DEFORMATION

The functions of the orbit deformation are:

a) to perform the orbit locally so as to enable the selection of a particular stationary ejection magnet out of several magnets positioned outside the aperture around the CPS;

b) in the case of fast ejection, to reduce to a minimum the amplitude of the kick required from the fast kicker;

c) to keep the internal beam out of the aberrant region shown in Fig. 2 either side of s. s. 57.

Functions b) and c) led to the choice of a 7-8 cm amplitude deformation centered on s.s. 59. Four pairs of speciall windings around the return yokes of 8 CPS magnets produce a deformation three half betatron-wavelengths long with an amplitude towards the outside twice as large as towards the inside. This arrangement ensures zero total induced voltage and leaves the orbit undisturbed in the rest of the CPS while keeping the ampere-turns per magnet at a reasonable value. The 8 windings with 8 turns each are powered from a SCR rectifier specially designed of fast rise (25 ms, required for efficient beam sharing) and for low-ripple flat top operation (± 1,5 ‰).

4. EJECTION MAGNET

The ejection magnet (11) consists of a 10 kG section 70 cm long with a septum of 3 mm and a 20 kG section 52 cm long with a septum of 6.1 mm (Fig. 3). It is powered from a 16 kA SCR supply with electronic filter (current ripple $< \pm 2‰$). The tank housing the magnet is designed as a plug-in unit, permitting the exchange of a magnet for another one in about 15 minutes.

(Fig. 4). The distance of the septum from the equilibrium orbit and its angle with the orbit can be adjusted by remote control.

5. EXTERNAL BEAM

A flexible design was adopted allowing one to provide a focus of either beam (i. e. slow or fast ejection) close by or to transport the beams out into the experimental hall (Fig. 5). Slim lens (12) Q 1 focuses the beam horizontally after the passage through the defocusing fringing field of the magnet unit 58; Q 1 has almost no action in the vertical plane because of the closeness of a focus. Lens Q 2 focuses vertically. Lenses Q 3 and Q 4 focus the beam onto the target; they are not energized for transport into the hall. The magnets B 1 - 8A serve to steer the beam away from the outside wall and onto the target at the required angle, magnet B3 is a vertical steering magnet. The lenses have a 5 cm bore; an elliptical aperture 6 cm × 4 cm may be used with 5 kG/cm gradient. The bending magnets have apertures 4 cm high × 7 cm wide; $B_{max} = 20$ kG.

6. BEAM OBSERVATION AND MONITORIG

Beam observation and monitoring was done by means of closed-circuit TV and a variety of screens (decreasing in sensitivy from that of the fluoroscopic type to $CdWO_4$, exchangeable by remote control), a solid state diode beam profile detector, Cerenkov counters, two beam current transformers optimized for 2 μs and 1.5 ms bursts respectively, and a secondary emission chamber.

7. PERFORMANCE

As far as could be ascertained in the short time available, the system behaves as anticipated from the design calculations (3) (13) at 12.2, 19.2 and 24.5 GeV/c. Reesonant ejection gives a particularly stable beam. The CPS lens settings for achieving this type of ejection are uncritical, within certain limits. Thus the horizontal beam width (2) and also, to a lesser degree, the beam orientation in phase space (3) can be varied over a considerable range by adjusting the strength of the quadrupole and sextupoles.

A nuclear emulsion exposed in the beam at the target position at right angles to the axis and the beam density distributions deduced from this by means of a microphotometer are shown in Fig. 6. Optical conditions were arranged to obtain in the horizontal plane a real image (in the sense of light optics) of the beam in the septum magnet with a magnifitation of 0.3. The density distribution in the horizontal plane is given by the beam spill out conditions; the distribution in the vertical plane corresponds to that of the internal beam.

The duration of the burst ejected is determined by the average rate of change of the synchrotron guide-field. Two typical oscillograms jof bursts from long-burst ejection (for counter experiments) and short-burst ejection (for bubble chamber work other than with r. f. separators are shown in Fig. 7. Electronic filtering of the CPS magnet ripple and fast feedback control of the spill out rate were used to obtain the smooth long spill (2).

For a beam 15 mm wide at the ejection magnet the ejection efficiency was measured as 70% using the beam current trasformers for the internal and external beam, an efficiency value in agreement with theory (2) (3).

The beam emittance was studied at 12.2 and 19.2 GeV/c by means of nuclear emulsions as described previously (2). The values obtained

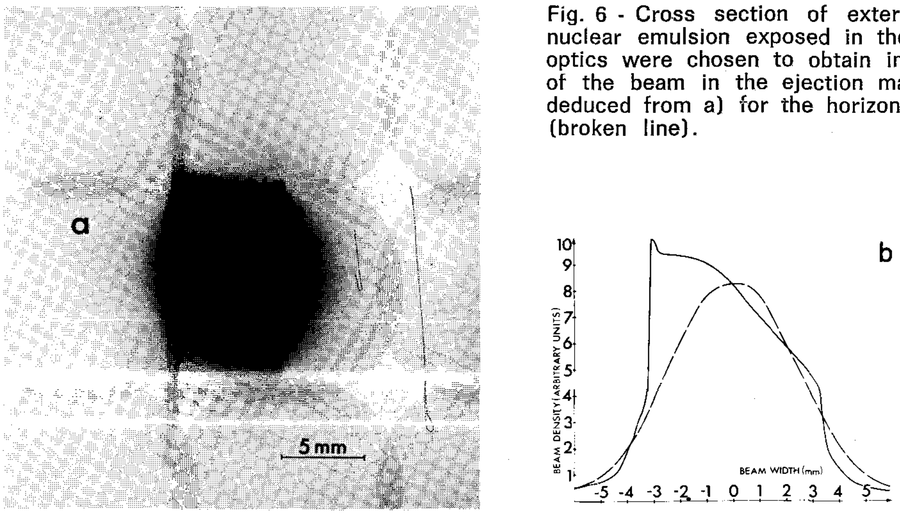


Fig. 6 - Cross section of external beam - a) Reproduction of a nuclear emulsion exposed in the beam at the target position. The optics were chosen to obtain in the horizontal plane a true image of the beam in the ejection magnet. b) Beam density distribution deduced from a) for the horizontal (full line) and the vertical plane (broken line).

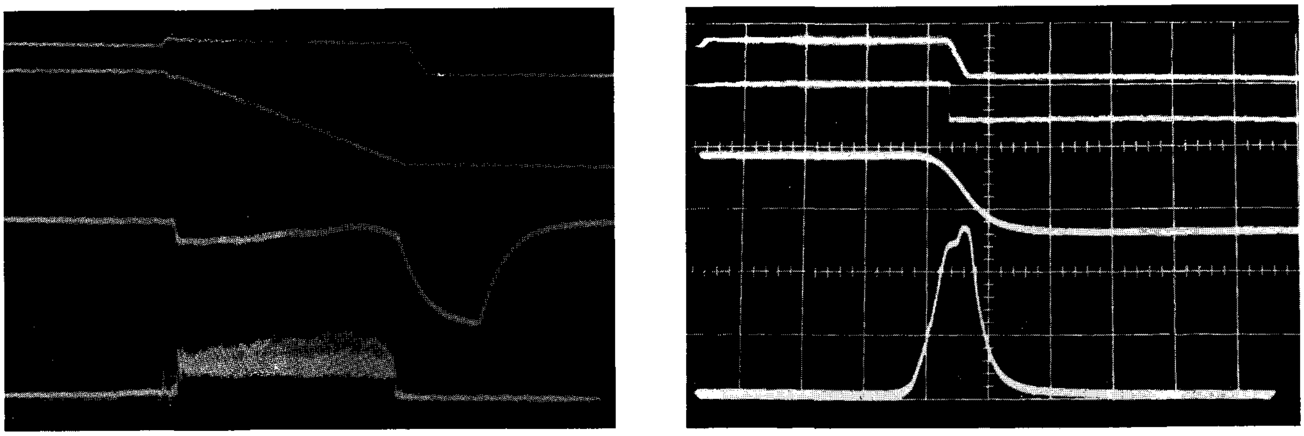


Fig. 7 - Oscillogram of beam burst produced by resonant ejection - **Left**: Feedback controlled long burst (~ 180 ms); Sweep: 50 ms/square; Top trace: Flat top of magnet cycle; Second trace: Circulating proton current; Third trace: Current in positionning CPS dipole controlled by spill out rate; Bottom trace: Signal from counter looking at external target.
Right: Short burst (~ 1 ms duration); Sweep: Two upper traces: 50 ms/square; Two lower traces: 0,5 ms/ square; Top trace: Flat top of magnet cycle; Second and third trace: Circulating proton current; Bottom trace: Signal from counter looking at external target.

at these momenta in both planes are respectively 0.8 ± 0.2 and 0.5 ± 0.1 in units of π mm mrad for 90% of the fast-ejected beam containing 4.10^{11} protons. The horizontal emittance of the slowly-ejected beam depends on the beam width chosen and also on the ejection efficiency since a fraction of the particles scattered by the septum stay in the external beam. The values measured in both planes under various conditions ranged from 1-2 times the figures given above. For the horizontal emittance this result is in agreement with previous measurements (2) and theory taking into account the ripple of the ejection magnet power supply.

The close similarity between the emittance values measured for the fast-ejected beam and those of the internal beam shows that the shimming of the CPS magnet was successful in reducing the non-linear aberrations (removing the shims from magnet 58 roughly doubled the size of the strongly focused spot at the target position). Apart from the beam emittance and optics the useful spot size at the target depends upon effects like beam jitter and dispersion. It was found that the strongly focused beam could be passed through a hole of 2 mm diameter in a ZnS screen without visibly touching the rim.

8. FUTURE IMPROVEMENTS TO THE SYSTEM

A kicker having the full CPS aperture (14), which will increase beamsharing possibilities (15) and facilitate the operation of fast ejection is under development. A scheme has been worked out (3) to increase the slow-ejection efficiency above 95% by focusing the internal beam during the last turn by means of a lens with a septum about 0.2 mm thick. It will be used for ejection from s. s. 62 in order to reduce the radioactivity induced the CPS and to obtain a cleaner external beam for physics experiments.

Acknowledgments

The design, fabrication and running-in of the ejection system from s. s. 58 has been the cooperative enterprise of the MPS Division. H. Fischer and G. L. Munday contributed to determining the basic design parameters. The R. F. Group (H. Fischer) was responsible for the ejection magnet and its power supply and controls, the electronic filter for the CPS magnet power supply, and the diode profile detector. The Magnet, Power, and Electrical Development Groups (A. Asner, M. Georgijevic, R. Mosig) carried out the shimming and shielding of the CPS magnet and provided the improved quadrupole 55 and the windings for orbit deformation, and their supplies and controls. In additions the Magnet Group designed and procured the " slim " beam transport elements. The Machine Utilization Group (G. L. Munday) was responsible for the vacuum system, the radiation shielding and the installation and alignment of the external beam. The Controls Group (J. H. B. Madsen) developed and built the feedback control system for the beam spill, the current transformers, the secondary emission chamber and the external target and provided the additional Main Control Room instrumentation required, including the TV system. The mechanical engineering was carried out by the MPS Drawing Office (L. Solinas) and most of the mechanical construction was done in the CERN workshops.

We would like to express our sincere thanks to all Groups for the efficient operation of their systems and for technical assistance during our tests and measurements. We equally appreciate the effort of the engineers-in-charge and the operators in running the CPS successfully under frequently varying conditions. We are indebted to K. Heyde and W. Kubischta for their help with the measurements and to the NPA Kicker Magnet Group (B. Kuiper) for bringing into operation the fast kicker 97 with the new ejection system. We are grateful to H. G. Hereward for several helpful discussions and to P. Germain and P. H. Standley for their continued interest and support.

REFERENCES

(1) H. G. Hereward: The CPS Resonant Extraction System, Int. Conf. on High Energy Accelerators, Dubna 1963, p. 690 and CERN Report AR/GS 61-5 (1961).
(2) C. Bovet, G. R. Lambertson and K. H. Reich: Measurements on Slow Beam Ejection from the CPS, CERN Report 64-35 (1964).
(3) C. Bovet: Variation des paramètres de l'éjection lente, CERN Report MPS/DL 65-6 (1965).
(4) R. Bertolotto, H. van Breugel, L. Caris, E. Consigny, H. Dijkhuizen, J. Goni, J. J. Hirsbrunner, B. Kuiper, S. Milner, S. Pichler and G. Plass: The Fast Ejection System of the CERN 25 GeV Proton Synchrotron, Int. Conf. on High Energy Accelerators, Dubna 1963, p. 669.
(5) S. Pichler: The Kicker Magnet of the CPS Fast Ejection System, CERN Report NPA 64-27 (1964).
(6) G. Auberson and K. H. Reich: Etudes préliminaires du faisceau éjecté lent, CERN Report MPS/DL 62-25 (1964).
(7) K. H. Reich: Ejection from Various Types of CPS Straight Sections, CERN Report MPS/DL 63-8 (1963). K. H. Reich: Further Thoughts on Primary and Secondary Beams from Various Straight Sections, CERN Report MPS/DL 64-13 (1964).
(8) C. Bovet: Aberrations dues au champ de fuite, CERN Refort MPS/DL 64-9 (1964).
(9) A. Asner, P. Bossard and C. Iselin: Orthogonal Analogue Plate Models help to solve Magnetic Field Problems difficult to be treated analytically, Magnet Technology Symposium, Stanford University (1965).
(10) J. Geibel, G. L. Munday and G. Weber: A Note on East Area Ejection Facilities, CERN Note MPS/EP, (1964).
(11) H. H. Umstätter: Septum Magnets with 10 and 20 kG Fields for Slow and Fast Ejection from the CPS, CERN Report MPS/RF 65-12 (1965).
(12) A. Asner: The CERN Slim Beam Transport Elements, Magnet Technology Symposium, Stanford University (1965).
(13) K. H. Reich: Specifications for the East Area Ejection System, CERN Report MPS/DL 64-14 (1964).
(14) H. Fischer: Sone Reflections on Full Aperture Kickers, CERN Report (63-24 (1963).
(15) O. Barbalat: Beam Sharing with the Full Aperture Ejection Kicker, CERN Report MPS/RF 65-1 (1960).

THE CERN MUON STORAGE RING

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(Presented by F. J. M. Farley)

A muon storage ring may be used:

to purify a muon beam by allowing time for pions to decay,

to extend the duty cycle of a pulsed accelerator

to use a multiple traversal target; but we are interested primarily in an accurate measurement of the muon magnetic moment. Here I must remind you of the muon (g-2) experiment carried out of CERN (1) in 1961. When polarized muons circulate in a magnetic field B the precession frequency of the spin relative to the momentum vector is

$$\omega_a = \frac{1}{2}(g-2)\,(e/m_0c)\,B \qquad [1]$$

By this means the anomalous moment, (g-2), was determined to 0.4% thus verifying the theory of quantum electrodynamics for muons to distances of order 0.2 fermi. This experiment was limited by the muon life-time of 2.2 microsec, which made it impossible to follow the precession for more than $1 - 1^1/_2$ periods ($T \sim 4^{-6}$ microsec).

In the new project we shall store relativistic muons of momentum 1.3 GeV/c thus dilating the life-time to 27 microsec. However as no factor γ enters in equation [1] the precession frequency will remain essentially unchanged and we should be able to see ~ 20 precession cycles.

Fig. 1 shows the ring magnet 5 metres in diameter with B = 17.2 kG. The magnet is continuous