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STATUS OF SOME U.S. PARTICLE ACCELERATORS IN SUMMER 1963

(Notes taken on trip 6th to 27th June 1963)

I. Specific Topics of More General Interest

1. Introduction

The notes written by CERN visitors to the USA [1) to 17)] and the Proceedings of the International Accelerator Conferences (1956, 1959 and 1961) contain rather comprehensive and detailed information on the major U.S. particle accelerators. The present notes attempt to bring this information up to date and to report on some more general lines of development.

Laboratories and accelerators visited are :

Argonne National Laboratory : ZGS

Brookhaven National Laboratory : AGS, Cosmotron

Cambridge Electron Accelerator Laboratory : CEA

Lawrence Radiation Laboratory of U.C. : Bevatron

Stanford Linear Accelerator Centre (SLAC) : 2 mile electron accelerator "The Monster"

Thus the only major accelerator not visited was the high repetition rate 3 GeV proton synchrotron at Princeton. (I learned from a visitor at Brookhaven that while having reached design energy, this machine is not yet in regular operation for physics research because of marginal intensity apparently due to difficulties with the van de Graaff injector.)

Subjects considered in the subsequent paragraphs are :

New accelerators

Developments in accelerator technique

Developments in experimental equipment

Trends in use of accelerators

Scheduling of experiments

Details of particular accelerators visited will be given in section II.

2. New Accelerators

The CEA is now in full exploitation devoting daily two 8 hours shifts of its 5 days' operations per week to physics. Main emphasis is on e-p scattering (using internal H_2 target), photo production etc. rather than on elementary particle research (for which machines like the AGS and CPS are considered more useful because of the higher secondary particle fluxes).

The ZGS is scheduled to be assembled completely in August 1963. Commissioning is expected to take several months so that first experiments could be on the air before the end of the year. They are somewhat ambitious as far as the first beams are concerned. Besides two unseparated pion beams a separated beam (kaons up to 4.5 GeV/c) and an external proton beam (for their neutrino experiment[18]) are scheduled almost from the start.

The Stanford Monster is supposed to be commissioned in mid 1966 and to be fully operational a year later. While electron scattering, photo production, muon experiments etc. are naturally expected to take a prominent place, the production of secondary particles will also be persued actively. R.F. separated beams of 15 GeV/c momentum and higher are scheduled for soon after start-up and a neutrino experiment for somewhat later. According to calculations partly confirmed by experiments at CEA secondary fluxes in the forward direction may be higher than for the CPS and electron contamination by far lower than the corresponding proton contamination. On the debit side are the short duty cycle (about 10^{-4}) and the stronger muon contamination (from muons produced directly by the primary electrons). The latter production is, however, strongly angle dependent so that the ratio secondary particles/muons can be varied at will within certain limits.

As far as planning of new accelerators is concerned, the recommandations of the Ramsay panel give priority to a 200 GeV PS at Berkeley and a 600 to 900 GeV PS at Brookhaven. With respect to the 150 million dollars 12.5 GeV FFAG, which is also recommended (though less strongly), some people (notably M. Schwarz) seem to feel that it might be more interesting to build a 5 GeV FFAG plus a PS of as high an energy as the money saved on the FFAG would buy (30 GeV or so, conservatively). Main reason for this higher energy, 2×10^{14} protons/sec machine would be the wish to make (1) μ scattering experiments with accuracies the same as present electron scattering experiments (it seems that above one GeV muons are more suitable for the study of the structure of the nucleon because of the increasing radiation correction in the case of electrons) and (2) neutrino experiments yielding 500 to 1000 events/day in hydrogen or deuterium. In the latter case high energy is required to obtain neutrinos above threshold for hyperion production. Other possibilities mentioned include a high energy linac plus fast cycling AGS or a more conventional machine and a H_2 bubble chamber of the order of 10 m long. The general impression was that the proposal for this particular type of machine may still undergo several modifications, if it comes off at all.

3. New Developments in Accelerator Technique

These include :

Remote handling of radioactive parts

Computer assisted operation

Targets and beam stoppers for high power beams

At the AGS a completely automatic target changer is being developped, involving automatic airlock, and target removal and replacement mechanisms. Besides changing over from one type of target to another during runs, this device will also be capable of disposing them into a container, thereby minimizing radiation exposure of operators.

Computer assisted operation is being provided for the ZGS. SLAC people are considering designing their controls for later addition of a fast local computer for "process control". In their case such a computer may be particularly useful for switching in additional klystrons, improve phasing etc. in between pulses (360 p/s) as a few bad pulses (of wrong energy or too large energy spread) may already destroy the vacuum chamber.

SLAC also has the problem of using electron beams containing eventually up to roughly 3 MW of power. Heat developed in standard target, and dumps is about 10 to 100 times larger than under current heavy duty conditions (e.g. in FTH linac triode).

4. New Developments in Experimental Equipment

Developments include :

Beam transport elements

Supplies for transport magnets

Separators

Magnetic horns

Monitors

Electronic components

Bending magnets and lenses are now more or less standardised, though there would not necessarily appear to be universal agreement how far one has to push general purpose designs. Argonne have bell-mouthing and end plates on most of their magnets (= bendings and lenses) as well as motorised jacks [19] while for instance Brookhaven people feel that end plates while convenient are absolutely necessary only when magnetic shielding is imperative (e.g. close to the accelerator). Berkeley people are so concerned about location of conductors in excitation coils (for picture frame bendings and quadrupoles), that they have lately specified fully transparent insulation (no tapes of any description) and developed the corresponding technique, a concern less encountered elsewhere except perhaps at the ZGS with reference to the coil of the ring magnet.*) Most active design work on magnets concerns currently special magnets for extraction schemes and external beams, notably for the AGS [20] Bevatron [21], CEA [22], Monster and ZGS. Special point already observed by other visitors : shorter delivery times than in Europe, ranging from 4 to 9 months for a first order and from about 2 to 5 months for a renewal order of the same equipment.

Power supplies are now generally of the solid state type though rotating machines still exist (particularly at the Bevatron [23] and the Cosmotron). While generally considered superior because of no need for constant supervision, solid state supplies would not appear to be judged as an unmixed blessing. Unfavourable comments include the following :

Take up valuable floor space

Average power factor of about 65% (notably at the AGS, the Bevatron, and the Cosmotron there seems to be at least a temporary shortage of a.c. power while at the CEA cooling water is somewhat marginal on hot days)

High running installation costs if supplies are located in experimental areas and connected to magnets on an ad hoc basis

Concerning the latter point L. Kerth said that at the Bevatron they estimate the total cost of connecting and disconnecting power supplies and beam transport magnets at 0.1 $ per 0.3 m of cable run, mostly salary of electricians. (Before last shut-down they had almost 30 km of cable installed.) This lead them to study the economics of a semi-fixed d.c. distribution system in the experimental areas. Points to be included in studies of this nature comprise size of area, a.c. and d.c. voltages used, degree of complication of rectifiers and controls etc. Mixed systems (i.e. some supplies centralized in a power house, others on the floor) are in use at the Bevatron and the Cosmotron, the CEA goes in for a centralized system while the AGS would appear to have in operation the most decentralized scheme. Besides considering the share of the salaries for electricians, the total cost of power supplies has naturally to be taken into account in the over-all economics of the various schemes. There seems to be a tendency to increase the number of power supplies (relative to the number of magnets) the more difficult it is to reconnect them rapidly. Thus, depending on the system used, the ratio magnets / supplies various roughly between 2 : 1 and 1 : 1.

As far as I could find out, all magnets are run d.c. practically everywhere (except certain magnets of extraction schemes of cause), though e.g. all Brookhaven magnets are of the laminated type. The general feeling is that the possible saving in power cost is hardly worth the additional complication of a pulsed system. Other reason : difficulty of making wire measurements on pulsed magnets.

Noted in passing : "Gun turret" pivotable spectrometers (Bevatron) weighing up to 120 tons (ZGS).

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*The reason is probably that in these special cases the aperture has to be used right up to the coil and high field uniformity is required.

Separator developments are going on particularly at the AGS, Argonne and at SLAC. As Claude Germain and Brian Montague visited these laboratories recently at length nothing new can be said here. Noted in passing : the experiments for spraying charges on to separator plates at Argonne, the better results with glass electrodes at Berkeley and the different r.f. separator design philosophy at SLAC.

Neutrino horns, both different from the CERN design, are now under construction at Argonne [13) 24)] and Brookhaven [25)]. The Argonne design involves a long low Z target (needed to obtain good efficiency despite higher primary beam emittance) and powering by a built-in high current transformer (longer current pulse required because of 1 ms burst from Piccioni extraction scheme). The AGS design (proposed by L. Lederman and inspired by fusion work notably at Los Alamos) involves a 800 kA gas dischange lasting some tens of microseconds. While its cost is now estimated to be of the same order as that of the CERN design, this horn is claimed to have the advantage of good focusing properties over the entire interesting forward region while causing no loss in walls etc. Also the devices may become less radioactive than the CERN horn. Prototypes have been built and operated for both designs and both horns are scheduled to be operational early in 1964.

As far as monitors are concerned, no magic all purpose, wide range (of intensities) device seems to exist. A new development may be the channel type electron multiplier or the windowless proton detector manufactured by the Bendix Corp., studied for use at the ZGS by J.Martin and favourably commented upon by G.L. Miller from Brookhaven (who has not used it).

As regards electronic apparatus it is felt in several places that (partly due to Space developments) industry is now so far advanced, that little room is left for home-built apparatus dealing with standard cases. Rather, commercial building blocks (modules) are being assembled for the purpose on hand. One firm making such elements is the Digital Equipment Corporation of Maynard (Massachusetts) [26)]

5. Trends in Use of Accelerators

The trend is naturally towards getting the highest physics output possible. Means used are :

7 day operation

Increased accelerated currents

Beam sharing

Faster data taking

Seven day operation is current practice at the AGS and the Cosmotron (while the Bevatron went back on a 5 day schedule for lack of funds).

The Bevatron is now running regularly at about 2×10^{12} protons/pulse (and they hope to increase this figure further), the AGS reached 6×10^{11} protons/pulse (with 25 mA from the Linac) during my stay and the ZGS will make every effort to reach the design figure of 10^{13} protons/pulse.

Beam sharing is common at all accelerators visited, usually between a bubble chamber and counter experiments (during the same pulse). In case of a Piccioni extraction scheme, secondary beams may be derived from the Piccioni target (Cosmotron, ZGS). For the Monster programmed changes of energy are planned on a pulse to pulse basis (360 pulses per second), for making it possible to run"simultanously" for instance an electron scattering experiment at 9 GeV/c and a separated pion beam at 15 GeV/c. (This implies the development of fast switching magnets in the "Switchyard".)

In the category of devices for faster data taking one has the new fast cycling 25" H_2 bubble chamber at Berkeley, which is expected to take somthing like 5 (x 3) pictures per Bevatron pulse. The Moyer Group contemplates running their spark chamber camera using continuous film motion (= "streak camera"), i.e. in a stroboscope mode. This is supposed to yield of the order of 100 pictures per machine pulse (5 to 6 per burst being considered as the present state of the art). Very large arrays of counters and/or spark chambers presumably also increase the rate of data taking in certain cases.

Other feature observed at the Bevatron which in a way comes also under the heading beam sharing : standby experiment set up in same beam behind (in series) with main experiment (by same group) so that switching over is rather fast.

6. Scheduling of Experiments

The system used would appear to be roughly the same everywhere, involving a high level steering committee for admission and a combined Users Machine Group Committee for practical realisation and medium to short term scheduling. I assisted to meetings called by the latter at CEA and AGS. There appears to be a noticable difference in proceedings between the more "family owned" machines like Bevatron and CEA and the "publicily owned" ones like AGS, Cosmotron and presumably ZGS. "Parasites" are usually served on a "what-is-left-over" basis, e.g. no special claims of any importance can be made.

II. Status of Particular Accelerators

1. AGS (visited from 20th to 27th June 1963)

Persons seen :

G.K. Green	Chairman of Accelerator Department
J.P. Blewett)	
M.H. Blewett)	
E. Courant)	
C. Lasky)	Senior physicists
M. Potkin)	
J. Spiro)	

E.B. Forsythe	Electrical engineer
W.G. Walker	In charge of floor operations
I. Polk	Head, Mechanical Engineering
L. Yuan	Senior physicist, Physics Division
M. Webster	Physicist in charge of beam corresponding to 0 2 at the CPS
G.L. Miller	Instrumentation Division

a) Accelerator

The AGS is now running continously (except two 8 hours' shifts for maintenance every second Monday), the mean intensity being somewhat above 5.10" p/p (peak 6 · 10" p/p). The additional 96 kicker coils are at present used for straightening out of the vertical losed orbit, improving the intensity by a factor of about 1.5 . New timing controls for ring magnet power supply are in operation. Peaking transformer for reproducible flat top field control is being installed. Ultimately, computer control of optimum cycle is planned. The vacuum in the linac tank is now 2.10^{-7} torr and on average the pressure is $5 \cdot 10^{-7}$ torr in the ring chamber, except in target area. Plans for future improvements include :

Rebuilding of linac r.f. system (to take care of increased beam loading by higher currents, partly brought about by increased bore diameters of first 10 drift tubes).

Study of possible modification of ring r.f. system in particular removal of 1000 A transistorized tuning (bias) supply to radiation shielded location (and perhaps replacement of transistors by SCRs with phase angle control), replacement of present 5 kW p.a. tube by a ceramic 20 kW longer life type (reduction of total number of accelerating stations from 12 to 8 with better ferrites is being contemplated), and substitution of solid state devices for the present tube equipped control circuits for cavity tuning (phase discriminator). In this application fast transistors will probably be used (though not needed for speed) because they were found to be less sensitive to radiation.

Automatic target changer referred to in I. 3 . - A somewhat special development concerning proton beam life studies in view of future AGS storage ring possibilities. To this effect the beam is accelerated to about 10 GeV, (with the magnet flat-topped at that level) and then held there. As the cavity bias supplies cannot normally be run continuously at this energy the beam is debunched upon reaching the flat top and then rebunched at the 4th harmonic (instead of the 12th), leaving out a few r.f. stations in unsuitable locations. This has worked for tens of seconds and is expected to be operational soon for tens of minutes (almost no bias current in r.f. cavity tuning circuit). Point to be studied will include influence of magnet ripple on beam loss etc.

b) <u>Extraction Scheme and Extracted Beam</u>

Installation of kicker (in L 10) and septum magnet (in A 10) is scheduled for the forthcoming 4 weeks' July shutdown. that of the extraction magnet (in B 10) for the 2 weeks' September shutdown.

Present status is :

Kicker magnet complete with pulse power supply fully assembled and working in air,

Septum magnet complete with transistorized power supply and moving mechanism fully assembled and working. 70.000 test cycles completed.

Extraction magnet being assembled.

The 4 sections, 5×10^{-2} T, full aperture (= 5 cm x 13 cm) kicker [27] has been designed as a "lumped circuit" element with 4 Ω impedance. Hydrogen thyratron switch (commercially available for voltages up to 40 kV, to be replaced every 6 months or so), matching capacitor and (small) load resistors together with auxiliary components are mounted on cover of vacuum tank containing kicker. One GE 7890 thyratron feeds two kicker sections in parallel, each drawing up to 2500 A current. (Latest thyratrons are rated up to 20 000 A.) Synchronization of the 2 thyratrons is said to be no problem if there is a reasonable voltage on the grid (in case of no success gradient grids would have been coupled together). The roughly 50 m long cable connection between the lumped element energy storage and the kicker may be used as storage for kicking out a single bunch. Sparking between the conductor (for the exitation) and the ferrite experienced with an earlier model was eliminated after extending the Teflon insulation to 6 mm from the cornes instead of 3 mm and rounding off the edge of the 1.5 mm conductor sheet (which is thinned down to half that thickness over its central part). The RC charging supply covers the range 15 to 45 kV. It is stabilized to $\pm$ 1/2%.

On comparing lumped and distributed inflector magnets [28] , E.B. Forsyth considers as the main advantage of the first one that (i) the construction is greatly simplified (flat Ferrite slabs glued together with Vinyl cement at 150° C) and (ii) the shunt capacitor can be a commercial item mounted on the load. He feels that the shunt impedance of such an element could probably be brought down to 3 Ω and that some impedance mismatch could be tolerated

The septum magnet has aperture 12.7 mm x 30 mm. The septum consists of commercially available copper clad (1 mm) stainless steel (0.3 mm) with the stainless steel extending beyond the gap for fixation and cooling. For a field in the gap of 0.2 T the stray field outside at 1 mm from the septum (measured with a long coil) was found to be $< 7 \times 10^{-4}$ T. (The $5 \cdot 10^{-2}$ T x 1.5 mm kick by the kicker will displace the beam by about 15 mm at top energy; jump due to septum magnet 35 mm). Some difficulty was experienced with the insulation of the septum. This problem may be eased by cutting the outer edges of the gap under a 45° angle and shaping the copper conductor correspondingly. According to M.H. Blewett the stray field should then at the same time be several times smaller (for the same insulation thickness).

The 2000 A supply for the septum magnet consists of 200 power transistors (2 N 174) servo controlled from a 100 mV current shunt. Current rise time is 15 ms, flat top length up to 250 ms and closed loop cut off frequency 2 kHz. Interlock circuits protect against overtime, overvoltage and overtemperature. The latter (thermocouple of 1 ms time constant) may be too slow. In the limit an infrared detector with a 1 ms reponse observing through a quartz window could be used (commercially available e.g. from Barns Engineering, Stamford, Conn.) The supply will be located 60 to 90 m from the septum magnet. Indications in the control room will include a digital display of exitation current and a measurement of septum temperature.

In a future version E.B. Forsyth would like to study the possibility of replacing the 200 power transistors by a few phase controlled SCR mounted in parallel. The ram [29] consists of a single hydraulic cylinder and "push" bar connected to the magnet. 2 supports and 2 equalizing bars. Radial end position of magnet is changed by bodily moving cylinder (the piston always moves with full stroke). The stroke is almost completed in about 100 ms, magnet reaches final position in about another 100 ms.

The outer coil of the straight 1.5 T ejection magnet (outward force about 50 kg/cm) is retained by an outside sheet. As in the case of the septum magnet, 3 magnets have been ordered straight away : 1 pair for neutrino area beam, 1 pair for bubble chamber area beam and one reserve pair.

For the moment powering of the ejection magnet (rated for d.c. operation) will be from a resonant (100 Hz) 8 k Joule capacitor bank (I max. = 7 kA). Magnetic flux will be sampled using a 100 μs gate at the peak of the cycle and the voltage of the charging supply regulated accordingly. Stability is expected to be 0.1 %; voltage can be changed by a factor of 2 in about 20 pulses.

For the "north" ejector magnet (located in I 10) C. Lasky plans an arrangement similar to that for SEM at the CPS : store position at the inside of the tank (allowing running of secondary beams from targets in same straight section), and standby and working positions at the outside (spaced about 6.5 cm apart; magnet to be moved by that distance every cycle). Change-over from store to standby position is expected to take about 10 minutes (motorized drives).

In addition to some existing 10 cm aperture quadrupoles the neutrino beam requires mainly 6 "pitching" magnets [20] (7.5 cm x 10 cm aperture) used to steer the beam up by about 3° and level it again to follow the 5 m difference in level between AGS ring and Neutrino Area. These magnets were designed to be powered in series from a single 450 kW supply.

E. Courant continues calculations on a resonant slow extraction system based on the $Q = 8.5$ resonance. As the border between the stable and the unstable phase space is not infinitely sharp and narrow, he would like to establish how slow one can traverse it and still keep good ejection efficiency. L. Yuan feels that physicists would like a spill of at least 20 to 30 ms and preferably as long as 200 ms.

c) Experimental Areas

Main beams used are the separated ones (no.1 into 20" B.C. filled with deuterium, no. 2 delivering 950 MeV/c K^- into the 30" HBC) and the muon beam. Setting up of the beam for the 80" HBC (operated successfully on 2nd June 1963 for the first time) has started. This beam will inter al. feature Tungsten alloy collimators (specific density 17), several Panofsky quadrupoles (partly chosen for higher acceptance, partly because not enough 30 cm aperture lenses were available at the time; require octupole lenses for correcting aberrations), specially shimmed bending magnets (to take out 6 and 10 pole terms), two 30 cm aperture weak sextupole lenses (0.1 T on pole), large air-cored vertical steering coil (of about 3 m length), two times 3 separator tanks of 5 m each, coupled together, and finally about 20 m of heavy concrete shielding between target and 80" HBC. This beam is expected to need about 10 MVA a.c. power out of the 18 MVA available for experiments at the AGS.

Beam transport magnets and supplies are still essentially of the types described by F. Grütter [5]. Main additions are 45 kW and 90 kW supplies. Present numbers have been transmitted to G.L. Munday.

The gas-discharge type neutrino horn [25] has already be mentioned in I, 4.

Some new storage and assembly area will become available soon so that the "outer" experimental hall can be freed somewhat. Noted at AGS and Cosmotron : light weight, inexpensive halls with A type cranes on rails.

d) Instrumentation

G.L. Miller is building a secondary beam scanner incorporating 32 home-grown lithium drifted silicium diodes of dimensions 1.5 mm x 1.5 mm x 2 mm deep. The device (of about 1 m x 1 m x 0.1 m dimension) looks rather impressive with its built-in amplifiers, storage and address systems. Even so the authors are not yet quite sure to what extent the signal/noise ratio will be satisfactory when observing minimum ionizing particles. As far as solid state intensity monitors for an intens. extracted proton beam are concerned, they have no particular experience themselves.

On studying the pulse height distribution obtained from solid state diodes in π+ p beams of momenta 1 to 6 GeV/c, L.C. Yuan and G.L. Miller found essentially no increase of peak height with higher momentum. In their view this was to be expected in view of the operative electron hole pair creation mechanism as distinct from ionisation loss. At lower momenta the proton peak and the pion peak could be clearly separated (with individual curves following a Landau distribution).

Noted in passing : d.c. panel meter withstanding 10^4 % continuous overload, needing two 10 mm holes for mounting (i.e. no cut-out) and incorporating a nylon pointer. (Parker Instrument Corporating, 200 Harvard Avenue, Stanford/Connecticut).

2. Bevatron (visited 10th - 12th June 1963)

Persons seen :

E.J Lofgren	Group Leader
L.B. Cork) L.T. Kerth) G.R. Lambertson) W.A. Wenzel)	Senior Physicists
W.D. Hartsough	In charge of Bevatron operation
B. Salsig	Chief mechanical engineer for Bevatron
A. Lake	Magnet designer
T. Jackson	Electrical engineer

a) Accelerator

The Bevatron improvement programme has by now been implemented to a large extent. The accelerator is regularly giving about $2 \cdot 10^{12}$ p/p with neither the linac nor the injection or trapping being a limitation for higher current. (This is why e.g. work on lower $\dot{B}$ at beginning of cycle has low priority). The 300 ms flat top just came into operation during my visit. Its use descreases the repetition rate from 12 pulses/min to 10 pulses/min or 9.3/min on very hot days (at full energy of 6.2 GeV, which is used normally). Without flat top, typical target operation involves for instance a 400 ms burst (E proton = 2.6 to 4.8 GeV) followed by a short burst 200 ms later (E proton = 5.7 GeV). Long bursts are obtained by dropping particles out of phase stability and making them interact with glass fiber targets (nylon targets as used previously could no longer stand higher intensities). The magnet ripple compensation (by menas of pfw) has improved the burst shape notably. A rapid beam deflector is used for short bursts of 350 μs maximum duration. Besides the rebuilding of the injector and the shielding, the r.f. system was completely overhauled, partly rebuilt and repositioned. The B integrator is now located in MCR, the driver and final amplifier in the dentre near the north straight section (which houses the r.f. station).

Improvements in MCR include updating of displays, addition of instrumentation and controls for new injector and external beam, and improvement of the indication of the radial beam position. A radiation control system complete with TV monitors and door interlocks (essentially similar to the CPS scheme) has also come into operation recently.

One good result of the improvements is that Bevatron operation is now found to be much more stable and regular (e.g. no "rep. rate effect" any more).

For budgetary reasons operation was cut back to the time from 4 p.m. Monday to 4 p.m. Saturday (with the time 8 a.m. to 4 p.m. on Monday being used for maintenance). Thus 3 crews for operation are needed instead of the 4 required previously. In view of the newness of the 19 MeV linac, there exists, however, now an additional injector operations group.

b) Extraction Scheme and Extracted Beam

The basic scheme [30] involves an energy loss target (in South s.s.) a first set of a internal deflecting and focusing of the Panofsky type magnets (M_1 + Q_1 in East s.s.), a second similar set equally plunged into the aperture at every cycle (M_2 and Q_2 in South s.s.) and finally an internal collimator (position adjusted according to energy) and beam exit port (in West s.s.) with bending and focusing following immediately afterwards (M_3 and Q_3). According to W.A. Wenzel the measured vertical emittance of the ejected beam is 30 mm mrad, while the horizontal emittance is several times larger. With the use of M_3 and Q_3 , a focal spot 2.5 mm vertical by 12.5 mm horizontal, containing about one-third the circulating beam is obtained within the main shielding wall of the accelerator.

M_1, M_2, Q_1 and Q_2 are powered by solid state rectifier supplies complete with magnetic amplifier control and transistor shunt. The latter is fitted with a watercooled heat sink, the total power absorbing capacity being about 12 kW. For ejection during the rising part of the main field these magnets (which work in the linear region) are tracked by means of the integrated $\dot{B}$ signal used for the r.f. programme. Indication of magnet current in MCR is by a four place digital voltmeter. The quality of the tracking corresponds to the precision of its indication. Also in MCR : controls for these magnets. Following the modern trend, the younger magnets M_3 and Q_3 (run d.c.) are powered by SCR supplies.

Observation of the external beam (to which I assisted) is by means of large scintillators and television (10^9 minimum ionizing particles on 25 mm quartz scintillator 25 mm thick with videcon, with orthocon one can go lower), or, for better resolution, by means of a small scanning scintillator and counter. X-ray film (10^8 to 10^9 particles per 25 mm squared) and radiographs (off polyethelene exposed to about 10^{13} to 10^{14} particles) are also used. A kind of thick "grid" consisting of a number of 12 mm square Cu conductors with a central hole joined together into a block with square cross section was used for some of the emittance measurements.

Intensity will eventually be measured with a beam current transformer (in air) of 75 mm internal diameter having a 2000 turn winding and supposedly measuring a 5 ms burst to 1%. (Transformer was being installed during my visit). Present intensity measurements were mostly made with a 10 gap ionisation chamber [31] filled with a mixture of 93% Argon and 7% Methane. The same apparatus can also be used as secondary emission chamber.

Magnet M 3 is rather similar to the first d.c. magnet for the slow ejected beam from the CPS (asymmetrical picture frame), further magnets for external beam are of standard design. First experiments involve p-p scattering from a thin target and scattering from a polarized target placed further down the beam.

c) Experimental Areas

Magnets will soon total about 25 bendings and 60 quadrupoles [23], the latter being increased by about 50% over previous figures (mostly AGS design with 20 cm and 30 cm bore). They are powered by 13 MG sets and 36 rectifier sets [23] (the newer ones of the SCR type). Indication is on small 4 place digital millivoltmeter (50 mV; 100 mV exists also, price 600 $). [32]

The H_2 targets are designed in such a way that they can stand power failures of reasonable length without any risk, therefore needing no no-break emergency power supply (air operated valves close vacuum gates in case of power failure). If power failure lasts longer, diesel powered generator could be started.

A d.c. separator fitted with glass electrodes and filled with Argon (at 1 micron pressure) is said to be operated at 550 kV over a 4 cm gap.

Special spark chamber set-ups and the fast cycling bubble chamber have already been mentioned in I. 5. The latter features expansion bellows (connecting the two chamber halves) made from 304 stainless steel; it will be used mainly for stopped K's.

3. CEA (visited 17th to 19th June 1963)

Persons seen :

Professor M.S. Livingston	Director
T. Collins)	
G.E. Fischer)	Senior physicists
R.A. Robinson)	
W.A. Shurcliff)	
G. Voss	In charge of operation

a) Accelerator

The accelerator has been working very regularly (19% down time during first 6 months of operation), the average intensity being 1.5 10^{10} electron/pulse (60 pulses/sec) and the peak intensity 3.5 10^{10} e/p. Depending on physics requirements, the accelerator is usually operated at energies between 1 and 6 GeV; length of target burst normally 500 μs. Operating is from Monday 8 a.m. to Saturday 8 a.m., the first daily shift being reserved for machine studies and setting up, the two others for physics. Maintenance is on Saturday (by technicians who come in on that day instead of Monday). Operation is by 8 E.i.C. (30% part time) and 20 technicians (75% part time). Shift crew comprises 1 E.i.C., 5 technicians, 1 electrician, 1 crane driver and sometimes 1 cryogenics expert (technician).

During the shutdown beginning on 15th July the MCR will be moved from its present temporary location to the centre building. At the same time it will be arranged in a more permanent fashion.

At injection mainly quadrupole correction (with pfw) is used, though a sextupole correction seems to improve things occasionally. The kickers for correcting the closed orbit are also being used, their proper setting up would, however, not appear to be very easy as the situation changes with time (also experienced elsewhere).

The 300 l Dryvac pumps are felt to be an acceptable state by now. Main concern relating to the vacuum chamber is about inside wall, which gets damaged e.g. from bombardment by electrons lost in the trapping process, and is not very accessable (all magnet yokes are on the inside). "Secondary" beams seem less worrying; a gamma ray beam is said to take several weeks to burn a hole into the chamber, which can then be repaired comparatively easily as hole is located at the outside. A new chamber is being designed at present, the top and bottom of which will be of the metal-strip-and-expoxy type used so far while the straight (in the vertical plane) sides are of plain aluminium sheet.

The internal H_2 target contains about 0.03 standard m^3 H_2 gas, which is liquified in the target proper (walls of mylar of 0.025 mm thickness) by means of liquid Helium. At injection the beam is steered around this target with the aid of special back leg windings used as kickers. Similar but much more powerful windings are used for targeting (on to this or the more standard stationary targets located outside the aperture required for injection). They are energized by a circuit using an inductance for enery storage and an SCR as switching element. Remanent radiation around target area is about 300 mrem/hour.

b) <u>Extraction Scheme and Extracted Beam</u>

The scheme is based on the use of a non-linear resonance at Q = 6.5, involving a current sheet and ejection magnet. The sheet is pulsed with a current of 3000 A lasting 250 μs using an SCR (Westinghouse 221 D, r.m.s. current rating 400 A, hold off voltage 200 V exist now up to 700 V). From a measurement of the heating up of a lead block placed in a position of the ejection magnet (to be installed later), the ejection efficiency was estimated to be at least 50%.

The septum magnet [22] of roughly 8 mm high x 25 mm wide aperture has a profile giving both bending and focusing (to correct effects due to the fringing field of the ring magnet). Peak current density in septum is about 650 A/mm^2, peak temperature 125° - 150° C of which about 30° C are due to heating by the bombarding electron beam. The latter effect can be used to align the septum parallel to the circulating beam by making the temperature increase the same at various azimuthal positions.

Beam transport of extracted beam is by conventional quadrupoles (100 mm bore, same commercial design as used for the AGS external proton beam). The thinking of its radiation protection has not yet gone very far.

c) Experimental Areas

The 120 ton pivotable spectrometer has already been mentioned. Special magnets include a quadrupole cut along its vertical plane to yield a slim focusing element. Radiation areas (>5 mrem/h) are surrounded by standard fences fitted with red lights (lit when particular beam on) which are interlocked with beam acceleration.

Noted in passing : Radiation meters with very large scales; individual current meters on 3 phase a.c. distribution boxes with notice "please balance phases"; standard use of walkie-talkie for general intercommunication (including information whether beam is on or off). The main crane (on semi-circular rails) is said to run well after the design of the wheels had been modified. The 100 l/h Helium liquifier is expected to be operational in 6 months.

Starting during the July shutdown, a new counting room will be added on top of the accelerator (earth shielding to be replaced by concrete) outside of the present experimental hall.

4. Cosmotron (visited 2oth and 21st June 1963)

Persons seen :

L.W. Smith	Group Leader
M.W. Barton	Senior physicist
A. Schlafke	In charge of floor operation and liquid hydrogen facilities

a) Accelerator

The Cosmotron is run continuously with one hour off daily for inspection and (small) maintenance. Intensity is about $3 \cdot 10^{11}$ protons/pulse (10^{12} p/p highest ever). The operating crew consists of 1 engineer and 9 technicians and sometimes 1 cryogenies technician per shift viz. E.i.C., 2 MCR, 2 P.H., 4 floor control room (2 for floor, 2 for beam transport supplies), 1 mechanic (water pumps etc.). Noted in MCR : home-built C.R.O. (using Tektronix circuits as far as possible) with 25 cm screen diameter and 10 traces (2 guns and choppers) for display of principal signals.

The shape of the flat top is controlled by means of a diode function generator steering the phase control of the ignitrons. It is set to give a 200 ms target burst with minimum modulation. They think about using a first harmonic distortion of the orbit to get a square shaped burst.

b) Extraction Scheme and Extracted Beams

Two simple (i.e. no special focusing inside Cosmotron) Piccioni schemes are in operation, using each an energy loss target and a fixed ejection magnet, shimming of Cosmotron field and external focusing as close by as possible. A more refined scheme perhaps based on the one proposed by Hammer (Mura) is being thought about, mainly to increase the efficiency above the 25% obtained at present in beams [33] no 1 and 2 (fed from ejection magnet in West s.s.). Efficiency for beam no. 3 (fed from magnet in South s.s.) is 60% (traversal of fringing field at steeper angle).

Rough observation of external beam is by means of Na I crystals, grids and light sources (with television), the dynamic range of which is, however, quite limited (not at the detector level). The electronics of the television display permits one to blank at a preselected intensity so that a number of contours may be obtained, thereby mitigating to some extent the ill effects of the small dynamic range. Usually Polaroid film type 57, 3000 speed (10^9 protons/cm^2) is used for checking the beam focus. A 3 plate ionisation chamber [34] is used for the routine monitoring of the external proton beams. It is filled with 90% Argon and 10% Methane under slight overpressure. Designed for 900 V, it has run at 1100 V. Observing the usual precautions (cleanliness, absence of water vapour, no sparking, leads out of beam) a linear indication is obtained in the range of interest (up to about $5 \cdot 10^{10}$ protons in 2 ms). Calibration is with activation of carbon foils in same beam.

c) Experimental Areas

80% of the physics at the Cosmotron is done by outside groups, who normally bring their own detection apparatus. With the exception of a secondary beam from the West Piccioni target (previously pions, now neutrons) and a simple test beam from the same target, all beams are derived from external targets [33]. After some experimentation with 2 targets in the same beam, it is now standard practice to run a single experiment per external proton beam at a time (others on standby in the same beam or being installed in other beams).

The policy has been to shield external beams such that radiation level in Hall still allows access under usual conditions. (This is necessary, e.g. to install a new experiment while old in progress in view of the fact that the accelerator operates continuously with practically a single experimental hall). This requires normally 12 m of heavy concrete for the beam stopper, 1.8 m for the side walls and 1.2 to 1.8 m for the roof of the shielding tunnel. Large amounts of steel are used more often than concrete to stop the beam.

Before switching on an external beam the shielding "caves" are inspected by the floor crew and then locked. Control of magnets up to first focus is by Cosmotron people from there on by experimenters (if so they wish, as with secondary beams).

Noted in beam no. 2 : secondary beam strongly sloping upwards to obtain enough clearance for spark chamber detector complete with mirror arrangement.

5. Stanford Linear Accelerator (visited 6th to 8th June 1963)

Persons seen :

Professor W.H.K. Panofsky	Director	
K.L. Brown	Leader of Instrumentation and Controls Group	
K.E. Breymayer K.B. Mallory D.A.G. Neet	Members of Instrumentation and Controls Group	
J. Ballam	Leader of Research Group	
F. Bonaudi	Beam Layout	Members of Research Group
H. Brechna B. Hedin	Magnets	Members of Research Group
E. Garwin	Targets and dumps	Members of Research Group
R. Larson	R.F. Separators	Members of Research Group
R. Taylor	Switchyard	Members of Research Group

a) General Situation

The two-mile $ 114 million linear electron accelerator [35] (project M, the Monster) is scheduled to give a beam in Summer 1966 and to be ready for full scale research a year later. At present the 200 hectar site (= 5 x old CERN surface area) is being developed with about a third of the stage I buildings-up and the digging of the ditch for the linac about half finished. Of the 500 present staff (to reach 700 in the next years) most are still housed in temporary quarters near the Stanford campus ; they will, however, move to new site (about 10 km away) this summer and autumn.

Design of accelerating structure is practically frozen, details of beam switch yard are being finalized while end stations have not yet been given detailed considerations.

Main problems arise from high electron intensities (= high power and high radiation levels) and large number of components as well as precision requirements. To illustrate the first point : The maximum beam power will be 2.4 MW (at 10 to 13 GeV; 600 kW at 20 GeV), and a good x-ray beam may contain about 100 kW. As a result, to stop the electron beam will require about 7 m of water-cooled absorber. Also constructing materials have to be choosen carefully, leading for instance in the switchyard area to adopting porcellan distance pieces and insulation for magnet coils and their current leads, respectively, and magnesium oxide for the insulation in signal cables. To illustrate the large number : The accelerating structure will consist of the order of 10^5 "cavities" made up from individual copper cylinders and end disks, brazed together into sub-units and then into units, tuned one by one (by slight denting) to the operating frequency of 2856 MHz and finally assembled into the entire 3 Km long structure. As to the precision : The manufacturing tolerances for the accelerating structure (made by the SLAC Group themselves) are about 0.01 mm, the alignment over the 3 Km must not deviate (also in the long run) from a straight line by more than two centimeters or so (1 mm is hoped for using laser techniques) and the earth magnetic and any stray fields around this structure must be kept to very low values (of the order of 10^{-9} T). High precision optics is required for the injection (at various points along the structure for beams of energy less than the maximum one) and switchyard systems, because of the need to preserve the inherently small phase space area (about 5 mm x 10^{-2} mrad or better) of the electron beam and to avoid debunching (the accelerator being itself the "first r.f. cavity" of the r.f. separator scheme for secondary beams). In case of the injection the latter requirement means that various path length through the magnetic system must be equal to about 10^{-4} even for $\Delta p/p = \pm 5\%$. The uniformity of the standard magnets in the switchyard is specified as $\Delta B/B = 10^{-4}$ with the magnetic length independent of horizontal position or field level.

Three main classes of experiments are envisaged at present :

i) Experiments with electron 1 positron and γ - beams (electron and positron scattering, photoproduction etc.).

ii) Neutrino physics (later)

iii) Experiments with secondary particles

Due to Drell type processes the production of π's, k's, $\bar{p}$'s etc. by electrons may be more copious than thought earlier (confirmed for π's at CEA), particularly in the angular range $\theta \lesssim \frac{m_\pi}{E_\pi}$ when pion energy $E_\pi \gtrsim 0.8\ E_{el}$. In this cone with half angle of the order of 1 mrad secondary particles fluxes are expected to be of the order of 100 times the fluxes from the CPS, with no strong p contamination in the case of positive particles. (Strongest contamination will be μ's with $\mu : \pi \approx 1 : 1$ at unfavorable angles, this being the reason for dumping the beam downward into the earth.) For counter experiments the low duty cycle (about 10^{-4}) of the Monster has to be considered too, of course, to make the picture complete. RF separated high energy secondary beams will be set up from the beginning of Monster operation.

b) Instrumentation and Controls

i) General control problems

These are rendered particularly severe by

- High power (Mark III already burns hole into vacuum chamber in 0.1 sec when mistuned)
- Multiple beams (change of energy from pulse to pulse, switching of primary beam into various target areas from pulse to pulse)

For protection the trigger will be turned off for 1 s for instance when radiation detectors etc. detect any significant change in beam condition.

ii) Instrumentation for beam monitoring.

In the accelerator beam position and intensity measuring devices are based on magnetic induction ("Hereward transformer").

In the switchyard the same principle is maintained for the intensity measurement.

The beam position will be measured either by means of microwave cavities or residual gas detectors, both still to be studied in detail [36].

In addition a beam energy spectrum analyser will be used for monitoring the spectrum produced in the accelerator [37]. It is based on secondary electron emission from a number of thin foils which may be placed into the beam by remote control at a location of known energy dispersion.

iii) Timing

The basic data are

Beam pulse length 0.1 to 2.1 μs

Pulse repetition period 2.7 ms $\pm$ 2 μs (360 pps)

Pulse to pulse reproducibility of timing sequence 15 ns

To garantee the last requirement timing will be made by means of a single (quartz crystal) clock and passive delays.

iv) Data transmission and display

Three types of systems :

- 100 x 30 on-off status indications (time division; transmitted during interval between pulses)
- 15 x 30 analog signals (meter readings etc.; frequency division centered on 10 KHz or so)

- Beam monitoring

  α) Position (to ± 1 mm or 5% permitting frequency division)

  β) Intensity (range 1 : 100, precision of 1% leading to binary code)

There will be 30 measuring stations (one per section, which is about 100 m long), however, simultanious display in MCR of 3 only is planned from the start.

Some multiplexing (time and frequency sharing) is planned; however, direct point to point cables will be used between MCR and each of the 30 sectors as distinct from an integrated multiplex system.

v) Use of computer

Use of a fast control computer for Monster operation at a later date is being considered.

c) Beam Switchyard

i) Layout and magnet system

The primary beam A (electrons, positrons, $\Delta p/p = \pm 1\%$, resolution 0.1%) and the secondary production beam B ($\Delta p/p = \pm 3\%$) have essentially the same layout, involving dispersion free optics and high quality magnets. Beam optics calculations have been developed particularly by K.L. Brown, using 4 x 4 matrices (including the path length) for analysis and including second order terms in the usual 3 x 3 matrices used for beam design [38] [39] [40].

ii) Targets and beam dumps

Three types

- Reliable final beam dump (no specification for instance on the atomic number Z)
- π production set-up (short - i.e. 0.5 to 1 radiation length - low Z target plus long high Z dump for electrons)
- μ production set-up (situation reversed with respect to choice of z of material; what counts is ratio radiation length/ n.m.f. path which changes from 0.21 for Al to 0.031 for H_g)
- Portable low power targets (for γ beam for instance).

Main problem is heating of beam dump. For a 3 MW beam the power delivered to a target per gram of target and unit cross section is about 4000 Z^2 watts. In the case of lead this gives about 160 kW/g x cm^2. Considering likely beam cross-sections this leads to a theoretical temperature increase <u>per pulse</u>

as follows :

	C	H_2O	Al	Cu	Pb	W
$\Delta T(^{\circ}C)$	15	20	120	900	1800	2200

Where possible water dumps (with artificial stirring of the water) are planned at present.

Related problems are the thermal stresses in the target, leading to considering such materials as T i C, T i B, W C and W B.

Another worry is the distruction of the material by the radiation, illustrated by the fact that the 10^{15} electrons per pulse will on average produce 4 x 10^4 dislocation each.

iii) R.F. Separators

B. Montague collected recently all the relevant information. A trial cavity will be experimented on shortly with the electron beam of the Mark KV accelerator.

6. <u>ZGS (visited 13th and 14th June 1963)</u>

Persons seen :

L.C. Teng	Director, Accelerator Department
J. Martin	Leader of R.F. Group
R. Perry	Leader of Linac Group
L. Ratner	Leader of Magnet Group
H. Vogel	Engineer responsible for magnetic horn
D. Jovanovic) T.A. Romanowski)	Physicsts, Physics Division

a) Accelerator

Linac is working, giving regularly 18 milliamperes to be injected in July into magnet octant no. 1 to test inflector. The other 7 octants are being mounted, simultaneously working 3 shifts, 7 days/week. The inner vacuum chamber is completed, the outer is mounted together with the magnet. The r.f. cavity was run at full voltage (20 kV); the ring magnet power supply is working (without load).

Expected characteristics as given to users include the following [41]. Physics programme to start after November 1963, one 8 hour shift/day, 10^{12} protons/pulse. Six months after this 10^{13} p/p may be reached (optimistically). By February 1964 there will be a 200 ms flat top; up to there a "round" top will be used.

b) Extraction Scheme and Extracted Beams

At first a conventional Piccioni system will be used, giving bursts as short as 500 μs duration; beam emittance π x 12.5 mm mrad [41]. Early next year a fast pulsed magnet is supposed to be available which will eject the beam in 20 μs [42].

Two versions of beam transport are under study[43], a "short" system for bringing the extracted beam to the magnetic horn used in the neutrino experiment and a "long" system guiding the beam to the dump behind the proton hall. Targets may be placed at intermediate foci. The "short" system involves 12.5 cm dia lenses 1 m long (2000 gauss/cm), the"long" system 25 cm dia lenses 2 m long.

For the observation of the external beam the usual range of apparatus is being contemplated. The "slow" beam current transformer is supposed to measure 10^9 protons in 2 ms. They are also interested in trying out solid state diodes and the Bendix detector mentioned in I, 4.

c) Experimental Areas

Magnets and lenses are of high grade design. Magnets have $\Delta \int B\,dl < \pm .03\%$ at 1.8 T over about half the radial aperture and the lenses no harmonic error $> .01\%$ over an aperture corresponding to half the bore diameter. Total numbers are 12 magnets (+ 3 on order) and 38 lenses (+ 12 on order). Power supplies are of the solid state mag. amp. type [41]. In addition there will be 40 m of separator.

Magnetic horn [24] and neutrino area [18] as well as the separated beam have also been mentioned.

Noted in experimental area (also at the Cosmotron and elsewhere) : water-cooled d.c. power cables capable of carrying about 1000 A and said to be very convenient (welding cable).

The Users Handbook [41] is somewhat different from the CPS one, containing e.g. more information on stores items. It contains also description of all magnets and power supplies in use, complete with manufacturers' names. About 35 universities are interested in working at ZGS as well as 6 Argonne Groups.

III. Some Notes by Members of CERN on Visits to the U.S.A.

(Incomplete, no criticism of any other notes implied)

1) J.B. Adams (BNL, LRL, Stanford); PS/Int. DIR 60-1

2) G. Brianti (BNL, LRL, Stanford); MPS/Int.CO 61-29

3) H. Fischer (BNL, Princeton, Bell); MPS/Int.RF 61-9

4) P. Germain (BNL); MPS/Int.DL 61-32

5) F. Grütter (beam transport at BNL); ENG/Int.DL 61-15

6) H.G. Hereward (Control desk of Bevatron) Letter to G.Brianti dated 26.2.1960
(Beam transport supplies at BNL); PS/Int.AR 60-16

7) M.G.N. Hine (BNL, Mura, LRL); PS/Int.TH 59-7

8) P. Lapostolle (R.F. Sep. at BNL, LRL, Stanford); PS/Int.AR 60-7

9) S. van der Meer and B. de Raad (BNL, MIT, Princeton, LRL, Livermore, Caltech); NPA/Int. 61-26

10) E.G. Michaelis (BNL); MSC-40/960, M 195 dated 14.12.1962

11) G.L. Munday (BNL); MPS/Int. VA 61-15

12) C.A. Ramm and C.J. Zilverschoon (BNL, Oak Ridge, LRL, Stanford); handwritten notes, undated (1957)

13) C.A. Ramm (BNL); PS/Int. EA 60-9
(BNL, Bell, CEA, MIT, ANL, Oak Ridge); NPA/Int. 61-11

14) W. Richter (Acc. Conference 1961); MPS/Int. VA 61-14

15) F. Schneider (Spark chamber at BNL, Columbia, Princeton); AR/Int. GS 61-1

16) P.H. Standley (CEA); MPS/Int. DL 62-9

17) C.S. Taylor (BNL); MPS/Int. Lin 61-1
(ANL); Lin 61-2 and 3
(LRL); Lin 61-4

Reports etc. Brought Back From the U.S.

18) R.A. Lundy et al; Proposal for Neutrino Experiment at the ZGS; dated 21st March 1963

19) Photographs of Argonne lens

20) Set of drawings of pitching magnets for AGS external beam

21) Set of drawings of first external bending magnet (M 3) for Bevatron external beam

22) Drawing of CEA ejection magnet

23) L.T. Kerth — Bevatron Magnets and Auxiliary Power Supplies; BEV-628 (B) Second Revision dated 2nd July 1963

24) H.F. Vogel — The Horn of Plenty; ANLAD HV-2 dated 2nd May 1962

25) I. Polk — Visit to Los Alamos Scientific Laboratory; BNL-AD Memo dated 4th April 1963

26) Digital Equipment Corporation : Modules (Description of hundreds of solid state digital circuit modules sold by this firm)

27) Photographs of AGS kicker magnet and supply

28) E.B. Forsyth — Comparison of Lumped and Distributed Inflecter Magnets; BNL-AD Internal Report EBF-2 dated 18th March 1963

29) Photographs of AGS septum magnet and hydraulic ram

30) W.A. Wenzel — Bevatron External Proton Beam; Internal Note BeV-763 dated 31st August 1962.

31) W.A. Wenzel — Sketch of Bevatron ionization chamber

32) Measuring circuit for Bevatron supplies

33) Plan of Cosmotron beams (survey plan no. 7 dated Septembre 1962)

34) Set of drawings of Cosmotron ionization chambers

35) K.L. Brown et al — Linear Electron Accelerator Progress at Stanford University; Report M 275

36) D.A.G. Neet — Considerations About Beam Switchyard Instrumentation and Control System; SLAC TN 63-47 dated 5th June 1963

37) D.A.G. Neet — A Beam Energy Spectrum Analyser for the 2-Mile Accelerator; SLAC TN 63-21 dated April 1963

38) K.L. Brown — First and Second-Order Aberration Coefficients of Wedge Magnets; SLAC TN 63-12 dated February 1963

39) H.S. Butler and J.J. Muray — Deflection Magnet Systems for the Primary Beam; SLAC M report no. 297 dated April 1962

40) H. Brechna — Parameters of Switchyard Magnets; Internal Note dated 24th April 1963

41) Argonne Users' Handbook, 1963

42) S.Suwa and A.Yokosawa — Fast Ejection System of ZGS; ANLAD SS/AY1 dated 8th Dec. 1962

43) S. Marcowitz, L.G. Ratner and A. Wattenberg — External Magnetic Lens System for the External Proton Beams from the ZGS; ANLAD SM/LGR/AW-1 dated 23rd July 1962

K.H. Reich

Distribution :

MPS Senior Staff
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