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April through June 1963
Kenneth C. Crebbin, William L. Everette, Calvin F. Hansen,
Glen R. Lambertson, and William A. Wenzel

April 7, 1964
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Lawrence Radiation Laboratory
University of California
Berkeley, California
April 7, 1964

ABSTRACT

The Bevatron beam was on for 82% of the scheduled operating time. There was one 68-hour scheduled shutdown this quarter. The external-proton-beam extraction system was successfully operated, extracting up to 50% of the circulating proton beam.

The beam intensity at full energy seemed to be limited at about \(2.4 \times 10^{12}\) protons per pulse independent of an increase in intensity at the start of acceleration.

Three new primary experiments were started this quarter.
I. OPERATION

The Bevatron operation record is shown in Fig. 1. The Bevatron beam was on for 82% of the scheduled operating time. Equipment outage accounted for 15.7%, and experimental setup accounted for 2.3% of the scheduled operating time. There were 68 hours of scheduled shutdown and 24 hours of holiday time this quarter.

II. SHUTDOWN

There was a vacuum shutdown from 8 a.m., June 3, to 4 a.m., June 6. The primary jobs were to modify the west thin-window frame and to install a collimator for the external beam. The window frame was cut back on the outside to allow the $M_3$ magnet to be moved into better alignment with the external beam. A collimator was installed just upstream from the thin window to remove the edges of the external beam which were of poor optical quality (see section IIIA of this report).

Secondary jobs included (a) checking the alignment of some sections of the travel-target track; (b) making the septum of the external beam magnets $M_4 Q_4$ and $M_2 Q_2$ thinner by removing excess material from the magnetic shields; (c) honing the tracks on $M_4 Q_4$ plunging magnets to repair damage caused by misalignment of the guides.

The beam channel for the Moyer experiment was set up, with the secondary beam coming out the port at the quadrant-III, 89-deg area.

Routing maintenance was done on the magnet, power supplies, and auxiliary equipment.

III. BEVATRON IMPROVEMENTS

A. External Proton Beam

W. A. Wenzel

The achromatic extraction system for the Bevatron employs an energy-loss (jump) target and two internal deflecting magnets, each accompanied by a small Panofsky-type quadrupole lens. The beam emerges from the accelerator approximately one betatron wavelength after the target. Maximum intensity for the extracted beam requires that the internal magnets be plunged into the aperture after injection. This is done by two hydraulic plunging mechanisms which accurately position $M_4 Q_4$ and $M_2 Q_2$ in 0.7 sec with strokes of 0.7 m. Hence full intensity in the extracted beam can be obtained for proton momenta down to 3 BeV/c. The beam has been extracted for momenta as low as 2 BeV/c, with some loss of intensity because of the aperture restriction. A small fraction of the beam can be injected and accelerated with the internal magnets fixed in their final position. To provide for extraction of the beam over a range of energies during a given Bevatron pulse, the radial position of $M_4 Q_4$ can be programmed mechanically to
Fig. 1. Bevatron operations schedule for April through June 1963.
compensate for the change in the "jump" distance with energy.

The current in each magnet is pulsed. To a first approximation, the slope follows that of the magnetic field of the Bevatron, but small corrections to this program are available if needed. In this way the extraction system remains "tuned" over a range of momenta.

Targeting is expected to be the same for the external beam as for secondary beams; in this sense the circulating beam can be divided among several targets during a given pulse. Operation with a magnetic "flattop" and with either a long or short beam spill is feasible. Because of the orbit distortions caused by the field of the rapid beam deflector, the extraction efficiency for the fast spill is reduced (by a factor of order 2) with the present system.

The beam emerges from the west straight section at an average angle to the initial orbit which varies from 3.2 deg at 3 BeV/c to 4.0 deg at 7 BeV/c. At this location the beam is well confined vertically (Fig. 2). The divergence of the beam indicates vertical and horizontal images 1.5 and 6 m, respectively, upstream from the point of initial exit from the Bevatron. About 75% of the emerging beam is contained in a horizontal width of 50 mm. There is evidence that the beam outside this width is of poor optical quality, for reasons that are not completely understood. Collimation inside the Bevatron has improved somewhat the quality of the beam available for experimentation. The extracted beam is monitored with a secondary-emission chamber and an ionization chamber. These have been cross-checked by activation methods. The intensity varies from about one-third to one-half the circulating-beam intensity, depending upon the degree of collimation. Because as was stated above, very little beam is lost on the magnets themselves, we assume that the major loss of beam during extraction occurs in targeting.

The emittance of the extracted beam has been measured with the help of the deflecting magnet $M_3$ and the quadrupole doublet $Q_3$, which produces a third image of the internal target at $F_1$ (Fig. 3). At 7 BeV/c the minimum image is 3 mm vertical by 10 mm horizontal (full width at half maximum). The emittance is about 30 mrad-mm vertical and 60 mrad-mm horizontal. These measured values are consistent with the emittances calculated from the initial beam characteristics and the estimated disorder introduced in targeting. The larger horizontal emittance is attributed to the greater horizontal size of the circulating beam, incomplete elimination of the dispersion, and larger magnetic aberrations.

**B. Magnet Foundation Subsidence**

The expected settlement of the Bevatron magnet as the shielding load was applied to the foundation was calculated. This calculation was based on previous measurements and estimates based on the total expected magnet settlement. The engineering consultants on the foundation work had recommended that (a) loads around the ring be balanced to within 10 to 20% of the final load, and (b) we keep a close watch on the settlement as the loading progresses.
Fig. 2. 6-BeV external proton beam emerging from the Bevatron.
Fig. 3. External proton-beam trajectory through the west tangent tank and Quadrant III leg-slab area.
Because of the work schedule and the delivery of the shielding blocks, uniform loading was not practical. A close survey was maintained of the magnet foundation and floor-area elevations. After loading to the extent that a settlement of 1.6 in. was expected, we saw only about 0.06-in. settlement of the foundation area. This caused some concern that we might experience a sudden rapid settlement. This did not occur. Elevation of the magnet foundation was surveyed weekly in the wind tunnel and the floor area just outside the outer shielding wall. Biweekly surveys of the elevation of the inner support columns for the roof areas continued through May 23, 1963. We then surveyed biweekly. Plots of magnet-foundation and floor-area settlement are shown in Figs 4 and 5. Additional survey points were added in the wind tunnel after the January 20, 1963 survey. The dotted line joins the points through this area in the January 20 plot, Fig. 4. In the floor-area survey (Fig. 5), survey points are occasionally covered by experimental beam channels. The dotted line joins the points through the missing-data areas.

C. Beam Limitation

G. R. Lambertson

With the completion of the new 20-MeV injection system, the maximum beam amplitude of the Bevatron increased to a level at which one may expect space-charge and beam-loading effects to be detectable. The present performance is described with particular reference to intensity-dependent effects.

The dependence of beam amplitude upon injected current is shown in Fig. 6. The upper curve gives the beam captured and accelerated through the first millisecond. The lower curve is the amplitude accelerated to full energy. It is evident that the fraction of beam lost during acceleration is greatest at high intensity. This loss, at any beam level, appears as a smooth attenuation during the first 50 msec of acceleration, up to 70 MeV, after which there is no further loss. It is of interest that the beam amplitude at full energy is limited to about 2.4X10^12 protons per pulse independent of an increase in intensity at the start of acceleration. Capture efficiency at low intensity is about 20%, a reasonable capture for the Bevatron with no r.f. pre-bunching. The overall amplitude of the captured beam is nonlinear above 4X10^12 protons, although not so dramatically limited as the lower curve. Present measurements are insufficient to determine the sources of these nonlinearities. Experiments are in progress to determine the nature of the loss during acceleration, and to increase the beam intensity.

D. Radiofrequency Acceleration System

Calvin F. Hansen

The r.f. system is under study as one phase of the program to determine the cause of beam losses. The following changes and tests have been tried with the conclusion that (a) there are no glaring deficiencies in the r.f. system, (b) the r.f. phase servo system operates reasonably well, and (c) there does not seem to be a problem of beam loading on the r.f. system, but more tests are necessary.
Fig. 4. Relative elevation of magnet foundation. Area shown is in the wind tunnel on the outer radius of the foundation. There is similar settlement at the inner radius (not shown here).
Fig. 5. Relative elevation of magnet floor area. Survey points are just outside the main shielding wall.
Fig. 6. Bevatron internal-beam amplitude vs injected-beam current.
1. **Phase Detector**

Minor changes were made in the phase detector circuitry to improve d.c. stability. Two major changes in the phase detector bandwidth were tested out. The existing bandwidth was about 2 kc. The new values tried were 100 cycles and 10 kc. No significant changes in machine operation were observed.

2. **"Dee" Capacity**

A 20% increase in dee capacity was tried. This test was made in an attempt to assess beam-loading effects on the r.f. system. No significant change in machine operation was noted.

3. **Programed Radiofrequency**

a. **Radiofrequency voltage shaping.** The temporary breadboard previously used for programing the r.f. turn-on shape was refined. The revised circuitry permitted (i) prebunching; (ii) rapid (normal) rate of rise; and (iii) slow (< 300 msec) rate of rise (see Fig. 7). The prebunch voltage increased initial beam pickup. Total beam accelerated was not appreciably increased.

b. **Programed 1000-A power supply.** The phase detector was disconnected and a programed signal was used to control the 1000-A power-supply output. This determines the frequency of the final r.f. amplifier. Radiofrequency tracking was obtained for the first 60 msec. No decrease in beam loss was observed.

IV. **EXPERIMENTAL PROGRAM**

The Bevatron experimental research program is summarized in Table I. Three new major primary experiments were started this quarter. Two experiments continuing from the first quarter ended this quarter. There was one short emulsion run this quarter. Three secondary experiments were started, with two of them continuing into the third quarter.

The first of the new primary experiments uses the 72-in. hydrogen bubble chamber and a separated K^- beam covering a momentum band from 2.2 to 3.3 BeV/c. This experiment continues the Alvarez group's study of K^-+p interactions, and extends the momentum range of their previous 72-in. bubble chamber runs from 1.1 to 1.9 BeV/c.

Among the topics of interest in this new momentum range, are the studies of the Ξπ and KK systems and K/K* exchange mechanisms.

At 1.80 BeV/c the reaction K^-+p → Ξ+K+π goes largely through the Ξ^*/2 (mass = 1530 MeV) resonant state. Other Ξπ resonances may exist at higher mass, or in the τ = 3/2 state. A comprehensive study of the Ξ^*/2 (1530) and a search for any new Ξπ states is under way.

The neutral KK system decays via K^0 K^0, K^+ K^- K^0 K^0, or K^0 K^- interactions. In the experiment we attempt to establish the quantum numbers of these KK final states for the above interactions.
Table I. Summary of Bevatron experimental research program, April through June 1963.

<table>
<thead>
<tr>
<th>Group</th>
<th>Experiment</th>
<th>Start date</th>
<th>End date</th>
<th>12-h periods</th>
<th>Hours</th>
<th>Pulse schedule</th>
<th>Pri. or sec. exp.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Internal groups</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alvarez</td>
<td>Study of $\pi^-$ interactions in the 72-in. hydrogen bubble chamber</td>
<td>3/23/63</td>
<td>In progress</td>
<td>74</td>
<td>768</td>
<td>1:1</td>
<td>P</td>
</tr>
<tr>
<td>Powell-Birge</td>
<td>Study of the decay of stopping 750-MeV/c $K^+$ mesons in a Freon bubble chamber</td>
<td>3/23/63</td>
<td>5/27/63</td>
<td>64</td>
<td>656</td>
<td>1:1</td>
<td>P</td>
</tr>
<tr>
<td>Trilling-Goldhaber</td>
<td>Study of the related $\Sigma$-$\Lambda$ parity (1.1- to 1.3-BeV/c $\pi^-$)</td>
<td>3/26/63</td>
<td>5/26/63</td>
<td>62</td>
<td>625</td>
<td>1:1</td>
<td>P</td>
</tr>
<tr>
<td></td>
<td>Study of the related $\Sigma$-$\Lambda$ parity (1.1- to 1.3-BeV/c $\pi^-$)</td>
<td>3/25/63</td>
<td>In progress</td>
<td>25</td>
<td>292</td>
<td>1:1</td>
<td>S</td>
</tr>
<tr>
<td><strong>Alvarez</strong></td>
<td>Study of $K^-$-p interactions in the 72-in. hydrogen bubble chamber</td>
<td>4/26/63</td>
<td>In progress</td>
<td>21</td>
<td>222</td>
<td>1:1</td>
<td>P</td>
</tr>
<tr>
<td><strong>Barkas</strong></td>
<td>Emulsion exposure in the 750-MeV/c $K^+$ beam</td>
<td>5/27/63</td>
<td>5/27/63</td>
<td>3</td>
<td>43</td>
<td>1:1</td>
<td>P</td>
</tr>
<tr>
<td><strong>Moyer</strong></td>
<td>Study of inelastic $\pi$-p scattering in the 500- to 1000-MeV/c range and elastic charge-exchange scattering in the 500- to 1600-MeV/c range</td>
<td>6/7/63</td>
<td>In progress</td>
<td>21</td>
<td>232</td>
<td>1:1</td>
<td>P</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>S</td>
</tr>
<tr>
<td><strong>External groups</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Argonne (Marcowitz)</td>
<td>Counter tests</td>
<td>4/1/63</td>
<td>5/16/63</td>
<td>41</td>
<td>425</td>
<td>1:1</td>
<td>S</td>
</tr>
<tr>
<td>Univ. of Wash. (Masek)</td>
<td>Spark chamber and counter tests</td>
<td>4/10/63</td>
<td>Continuing</td>
<td>3</td>
<td>23</td>
<td>1:1</td>
<td>S</td>
</tr>
<tr>
<td>Philco Space Div. (Rinehart)</td>
<td>Test of solid-state counters and spark chambers</td>
<td>5/24/63</td>
<td>Continuing</td>
<td>3</td>
<td>26</td>
<td>1:1</td>
<td>S</td>
</tr>
</tbody>
</table>

*a Time from start of run through June 1963.*
Fig. 7. Turn-on shape of radiofrequency voltage.
K or K* exchanges mechanisms may dominate some K^- + p interactions, such as K^- or p → Y_0^* + ω, generally yielding aligned ω's. The observation of such alignment may demonstrate the validity of these mechanisms and may simultaneously permit determination of the Y_0^* spins.

Two new experiments were started by the Moyer-Helmholtz group using the same extracted π^- beam and beam-transport system. The experiments continue the study of the resonance region in pion-nucleon scattering in the 500 to 1600-MeV region. The π^- beam passes through a first liquid-hydrogen target and is refocused on a second liquid-hydrogen target. The two experiments are run simultaneously.

The first experiment measures some of the final-state configurations produced in the inelastic scattering of π^- by protons in the π^- energy range from 500 to 1100 MeV. Primary emphasis is on the 500- to 750-MeV energy region in order to investigate in detail the behavior of the inelastic cross sections in the vicinity of the second pion-nucleon resonance. The inelastic reactions are studied to obtain necessary information for evaluation of conceivable models of the π-N interactions as well as to understand their effect on the 600-MeV resonance.

The second experiment is a study of elastic charge exchange of negative pions on protons in the region from 500 to 1600 MeV. The major effort is to determine the pion-nucleon phase shifts by studying the reaction π^- + p → π^0 + n.

V. MAGNET POWER SUPPLY

The magnet pulsing record is shown in Table II.

VI. BEVATRON-BUILDING RADIATION SURVEYS

W. L. Everette

The more pertinent radiation measurements made by the Berkeley Health Physics department are summarized in Table III and Figs. 8 and 9. These surveys show that particles other than neutrons contribute negligibly to the biological dose. Except for gamma rays resulting from neutron capture events, X and γ radiation are also of negligible consequence.

Table III describes the machine operating modes and beam intensities for the various surveys. Figures 8 and 9 give neutron flux in particles per square centimeter per second averaged over time. To interpret these units in terms of biological dose, one should recall that 10^7 n/cm^2 is approximately 1 rem.

Figure 10 is a plan view of the building floor and machine. Neutron measurements on the floor were taken at heights from 4 to 6 feet and approximately in the center of the building bay, disregarding the annex. Roof-level measurements were taken azimuthally over the center of the Bevatron magnet.
Table II. Bevatron motor-generator set monthly fault report.

<table>
<thead>
<tr>
<th>Month</th>
<th>4 to 6 pulses per minute</th>
<th>7 to 9 pulses per minute</th>
<th>10 to 17 pulses per minute</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pulses</td>
<td>Faults&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Pulses</td>
<td>Faults&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Jan.</td>
<td>1055</td>
<td>16</td>
<td>1684</td>
<td>5</td>
</tr>
<tr>
<td>Feb.</td>
<td>1590</td>
<td>152</td>
<td>4030</td>
<td>3</td>
</tr>
<tr>
<td>March</td>
<td></td>
<td></td>
<td>1479</td>
<td>1</td>
</tr>
<tr>
<td>April</td>
<td>1306</td>
<td>1218</td>
<td>8698</td>
<td>1</td>
</tr>
<tr>
<td>May</td>
<td>1291</td>
<td>181</td>
<td>3059</td>
<td>2</td>
</tr>
<tr>
<td>June</td>
<td>63896</td>
<td>5</td>
<td>179044</td>
<td>21</td>
</tr>
</tbody>
</table>

<sup>a</sup> 14 indicates an arc-back, 26 indicates an arc-through.
<table>
<thead>
<tr>
<th>Date</th>
<th>Survey</th>
<th>Beam intensity (p/pulse)</th>
<th>Targets</th>
<th>Shielding</th>
<th>Information reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/26</td>
<td>Building</td>
<td>BF$_3$ - fast neutrons</td>
<td>Internal</td>
<td>Powell</td>
<td>NOW</td>
</tr>
<tr>
<td></td>
<td>floor</td>
<td>$8 \times 10^{11}$</td>
<td>External</td>
<td></td>
<td>47</td>
</tr>
<tr>
<td>4/10</td>
<td>Shield</td>
<td>Ag(n,γ) - fast neutrons</td>
<td>Internal</td>
<td>Lofgren</td>
<td>90°, QIII</td>
</tr>
<tr>
<td></td>
<td>roof</td>
<td>$8 \times 10^{11}$</td>
<td>External</td>
<td>Alvarez</td>
<td>19°, QIII</td>
</tr>
<tr>
<td>5/17</td>
<td>Shield</td>
<td>Ag(n,γ) - fast neutrons</td>
<td>Internal</td>
<td>Same</td>
<td>Same</td>
</tr>
<tr>
<td></td>
<td>roof</td>
<td>$8 \times 10^{11}$</td>
<td>External</td>
<td>Same</td>
<td>Same</td>
</tr>
<tr>
<td>5/24</td>
<td>Building</td>
<td>BF$_3$ - fast neutrons</td>
<td>Internal</td>
<td>Powell</td>
<td>NOW</td>
</tr>
<tr>
<td></td>
<td>craneway</td>
<td>$1 \times 10^{12}$</td>
<td>External</td>
<td>Lofgren</td>
<td>80°, QII</td>
</tr>
<tr>
<td>6/28</td>
<td>Building</td>
<td>BF$_3$ - fast neutrons</td>
<td>Internal</td>
<td>Moyer</td>
<td>80°, QIII</td>
</tr>
<tr>
<td></td>
<td>floor</td>
<td>$3 \times 10^{11}$</td>
<td>External</td>
<td>Alvarez</td>
<td>19°, QIII</td>
</tr>
<tr>
<td>6/28</td>
<td>Same</td>
<td>BF$_3$ - thermal neutrons</td>
<td>Internal</td>
<td>Moyer</td>
<td>80°, QIII</td>
</tr>
<tr>
<td>6/25</td>
<td>Same</td>
<td>BF$_3$ - fast neutrons</td>
<td>Internal</td>
<td>Lofgren</td>
<td>80°, QII</td>
</tr>
<tr>
<td>6/25</td>
<td>Shield</td>
<td>Ag(n,γ) - fast neutrons</td>
<td>Internal</td>
<td>Same</td>
<td>Same</td>
</tr>
<tr>
<td></td>
<td>roof</td>
<td>$5 \times 10^{11}$</td>
<td>External</td>
<td>Same</td>
<td>Same</td>
</tr>
</tbody>
</table>

* The normal pulse rate is 11 pulses per minute (ppm).
Fig. 8. Bevatron building neutron survey, April and May 1963
Fig. 9. Bevatron building neutron survey, June 1963.
Fig. 10. Plan view of Bevatron showing locations of radiation-survey points.
ACKNOWLEDGMENTS


REFERENCES


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