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*Radiation
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BEVATRON OPERATION AND DEVELOPMENT
XIV

May, June, July 1957

BERKELEY, CALIFORNIA

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BEVATRON OPERATION AND DEVELOPMENT: XIV

May, June, July 1957

Walter D. Hartsough

October 24, 1957

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Contents

Abstract	3
Operation	4
Resumption of Operations Following the Shutdown	4
Pumpdown Curve	4
Operation at Reduced Magnet Voltage (Tap 5)	4
Reduction in Time Lost Owing to Vacuum-Tank Shorts	6
Experimental Facilities	6
Quadrant-Mounted Targets	6
New Gap-Mounted Flip-Target Mechanisms (MK 7)	6
Apertures for Secondary-Particle Beams at the North and West Experimental Areas	11
Injector	11
Induction-Electrode Beam-Monitoring Systems	11
Extended Secondary-Particle Beam Pulses	14
Short Secondary-Particle Beam Pulses	14
Magnet Power Supply.	16
Research	19
Acknowledgments	19

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ABSTRACT

The first half of this quarter was in part a continuation of the shutdown of the last period and in part a shutdown recovery period. The second half of the quarter was devoted to high-energy physics and chemistry research and to the extension and improvement in techniques of producing secondary-particle beams.

The principal physics research efforts were a continuation of the investigations of interactions of negative particles in hydrogen using the 10-inch liquid hydrogen bubble chamber; counter studies of the π^0 modes of heavy-meson and hyperon decay; and a series of twenty-one nuclear emulsion exposures to K-meson beams. During this period twenty emulsion stacks were exposed for thirteen external groups. Thirteen target bombardments were made for the chemistry group.

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OPERATION

Resumption of Operations Following the Shutdown

The shutdown that began on January 31 continued during the first month of this quarter. The scope, and in many cases, the details of the work undertaken during this shutdown period were described in the preceding Quarterly Report. The work was completed about the middle of May and on May 21 the magnet was pulsed for tests with the vacuum tank at atmospheric pressure. During this period of test pulsing the operation of the motor-generator sets and ignitrons was checked, an inspection of the magnet was made, and the pole-face-winding and pole-base-winding field-correction currents were measured and adjusted for reduced magnet voltage operation. Strain-gage measurements and evaluation of loads were made on the new three- and four-sector window stanchions and on the new magnet-winding end-support structures at the exit ends of Quadrant II and Quadrant III. The measured values of the loads agreed with the predicted values. Magnetic field measurements were made in the aperture of the magnet in the region where the magnetic field was expected to be perturbed owing to eddy currents induced in the new four-sector stanchion. The measured magnitude of the field disturbance was as predicted. The current in the field-correction coil on the four-sector stanchion was adjusted to minimize the field perturbation.

Pumpdown Curve

Pumping on the vacuum tank began on May 27. The pumpdown curve appears in Fig. 1.

Operation at Reduced Magnet Voltage (Tap 5)

On June 1, with a vacuum tank pressure of 1.7×10^{-5} mm Hg, magnet pulsing was resumed for continued bake-in of the ignitrons, for tests of the rf accelerating system, and for beam-tracking studies.

In an effort to effect an eventual reduction in lost beam time due to ignitron faults, operations commenced, and will probably be continued, at reduced magnet voltage - 14.25 kv (Tap 5) instead of the preshutdown value of 16.05 kv (Tap 3).

Operation at reduced magnet voltage necessitated modifications in the radiofrequency tracking system and its associated analogue-computer correction equipment, and in the injection timing parameters as well as in the pole-face-winding and pole-base-winding currents mentioned previously.

MU-14464

Fig. 1. Bevatron Pumpdown Curve (Four-month shutdown, January 31 to May 27).

Beam was accelerated on June 1 but frequency-tracking errors caused the beam to be lost after about 250 msec (0.5 Bev). Gas scattering due to poor vacuum resulted in a large loss in beam early in the acceleration cycle. Beam amplitude was 5×10^7 protons per pulse. On June 8 operations resumed for the physics and chemistry research groups. The maximum accelerated beam amplitude at that time, as limited by gas scattering, was 5×10^8 protons per pulse. The beam amplitude on July 1 was 2×10^{10} protons per pulse. The maximum recorded beam amplitude at full energy during this quarter was 6.2×10^{10} protons per pulse; the maximum injected beam was 300 microamperes.

A summary of the operating hours and Bevatron performance appears in Fig. 2.

Reduction in Time Lost Owing to Vacuum-Tank Shorts

During the recent rework of the magnet coil boxes it became evident that the major cause of many electrical shorts between the vacuum-tank skin and the vacuum-tank frame (probably since very early in the history of the Bevatron operation) was the many coil-box sheet metal clips that had become free and had fallen against the vacuum tank. In the course of the recent shutdown work these shorts were completely eliminated. Where it was possible, other electrical shorts that existed between sections of the vacuum tank were cleared. This effort resulted in reducing, almost to zero, the incidence of lost beam time because of operation of protective circuitry guarding the tank skin from damage due to electrical shorts.

EXPERIMENTAL FACILITIES

Quadrant-Mounted Targets

Table I lists the quadrant-mounted targets that were available during this period.

New Gap-Mounted Flip-Target Mechanism (MK 7)

A new gap-mounted flip-target drive mechanism, with variable electrical damping, and capable of lifting a 1-pound target in 100 milliseconds, has been designed and tested, and is in use in the Bevatron. During life test, this mechanism has been cycled more than a million times without a failure. It consists of two coils mounted at approximately right angles to each other (actually at 80°), one for electrical damping, joined to the target drive shaft in such a fashion that the drive shaft forms the apex of the right angle. See Figs. 3 and 4. By use of this mechanism, the target is driven "down" as readily as it is driven "up". During Bevatron operation this feature is a definite advantage, as multiple secondary-particle beam production is often limited by the rapidity with which targets can be erected and lowered. The driving and damping currents are gated alternately from one coil to the other; the drive current is constant during the target travel time; the damping current is programmed to obtain the desired rate of deceleration.

Fig. 2. Bevatron Operating Schedule
May, June, July 1957

Table I

Quadrant-mounted targets
May 27, 1957 to end of quarter

Quadrant	Azimuthal Location (Ref: west straight section)	Radial Location		Target material	Target size $a \times b \times c$ (in.)
		Outer-radius edge of target (in.)	Outer-radius edge of lip (in.)		
II	$1^{\circ}15'$	599-1/2	599-3/4	Polyethylene	$1/2 \times 3/4 \times 1/2$
II	$2^{\circ}16'$	601-13/16	602-1/16	Copper	$1 \times 1/2 \times 1/2$
II	$4^{\circ}32'$	599-9/16	599-13/16	Beryllium	$6-1/2 \times 3/4 \times 1/2$
II	$13^{\circ}09'$	601-1/16	601-1/4	Uranium	$1 \times 1/2 \times 3/4$
II	$13^{\circ}57'$	601-9/16 max (adjustable)	601-3/4 max (adjustable)	Beryllium	$4 \times 1 \times 11/16$
II	$16^{\circ}19'$	605-1/16 to inner radius edge (outer-radius target)	-----	Copper	$7/8 \times 1/2 \times 3/4$
II	$19^{\circ}58'$	601-1/8	601-5/16	Polyethylene	$1 \times 1/2 \times 1$
III	$35^{\circ}32'$	600-1/2	600-3/4	Graphite	$3-15/16 \times 1 \times 4$
III	$71^{\circ}42'$	599-5/8	600	Aluminum	$4 \times 1/2 \times 1/2$
III	$72^{\circ}43'$	599-3/4	600-1/8	Copper	$3-1/2 \times 1/2 \times 1/2$
III	$79^{\circ}06'$	596-5/16 to center of target	-----	Polyethylene	$1/8 \text{ diam.} \times 1 \text{ high}$

Beam $\longrightarrow$

ZN-1841

Fig. 3. New gap-mounted flip-target mechanism (MK 7). Down position.

ZN-1842

Fig. 4. New gap-mounted flip-target mechanism (MK 7). Up position.

It is expected that the mechanism will prove very reliable in service: the drive and damping coils and the target are all placed on a single two-bearing shaft, thus eliminating the heavily loaded linkages and the more difficult multiple-bearing problems that exist with the single-coil mechanisms.

Target-position information is provided by microswitch indications and by measuring the induced voltage in the second drive coil.

Apertures for Secondary-Particle Beams at the North and West Experimental Areas

Figure 5 shows the recently cleared beam channel between the magnet-coil windings at the outer-radius exit end of Quadrant II (west experimental area). This channel allows the unobstructed passage of secondary-particle beams, which exit through the tank skin via the two-sector window stanchion. The lower surface of the beam exit slot is a table capable of supporting lead shielding or beam collimation.

A similar beam-exit facility exists at the north experimental area. In this case, not only were the coil space and coil end-support structure cleared of obstructions, but also the magnet leg slab was notched to permit use of the full aperture of the four-sector stanchion. (The measured magnitude of the magnetic field in this notch is 3000 gauss when the magnet is pulsed to full field. The distribution of the field is nearly uniform.)

Other additions and changes in the experimental facilities were reported in the preceding Quarterly Report.

INJECTOR

Figure 6 shows the presently used method of obtaining voltage division on the ion-gun column. Aluminum tubing conductors with quick-disconnect fastenings tie the column gradient rings to appropriate points in the 480-kv power supply. This method has proved very satisfactory.

INDUCTION-ELECTRODE BEAM-MONITORING SYSTEMS

Two independent beam induction-electrode systems^{1, 2, 3} are in use at the Bevatron. The instrumentation associated with each system is new and is described in detail in a separate report.⁴ Each system is stable, self-calibrating, and provided with automatic readout and recording.

The system that uses the large induction electrode in the east straight section is used for accurate beam monitoring and for primary calibration

^{1, 2, 3} Harry G. Heard, Bevatron Beam Induction Electrodes, UCRL-3609, Feb. 1957; Previous Bevatron Quarterly Reports, UCRL-3519, Nov. 1956, and UCRL-3212, Nov. 1955.

⁴ J. T. Lavrischeff, Bevatron Induction-Electrode Beam-Monitoring Systems, UCRL-8010, Oct. 1957.

ZN-1843

Fig. 5. West experimental area—outside radius. Unobstructed beam-exit slot between magnet coils.

ZN-1844

Fig. 6. Injector ion gun. Voltage division on the column is accomplished by connecting the column gradient rings to appropriate points in the power supply.

of other beam-monitoring equipment. The frequency range of this system, as limited by a band-pass amplifier, is 2.0 to 2.5 Mc (0.6 Bev to 6.2 Bev). The operating range is from 1×10^6 protons per pulse to 10×10^{11} protons per pulse.

The induction electrodes in the south straight section are primarily used for beam-tracking information, i. e., beam magnitude and beam radial position, and for information supplied to a radio telemetering system. The operating range of this equipment is 1×10^7 protons per pulse to 10×10^{11} protons per pulse. The frequency response of the amplifiers used for oscilloscope presentation signals is 100 kc to 20 Mc. The frequency range of the meter-readout and chart recording system is 2.0 Mc to 2.5 Mc (0.6 Bev to 6.2 Bev).

EXTENDED SECONDARY-PARTICLE BEAM PULSES

The method of producing secondary-particle beam pulses by expanding or contracting the orbit of the primary proton beam bunch⁵ has been extended in its application to include the production of extended beam pulses. A variable-amplitude sawtooth generator has been incorporated into the beam-programming controls of the Bevatron. The output of this unit is introduced into the shaper supply of the rf accelerating system. The perturbation that results in the output current of the shaper, and therefore in the rf frequency applied to the accelerating electrode, causes the beam to deviate from its normal orbit in a programmed fashion. In this manner, secondary-particle beam pulses of 500 milliseconds or longer have been produced (Fig. 7).

The structure of secondary-particle beams produced by driving the beam onto inner-or outer-radius targets by use of this method exhibits phase-oscillation structure, radiofrequency structure, and magnet-ripple structure. The energy spread of the primary protons striking a target during the pulse is determined by the duration of the pulse.

SHORT SECONDARY-PARTICLE BEAM PULSES

A method of producing short secondary-particle beam pulses has been used which involves trimming the radial width of the primary proton beam before causing the main beam bunch to strike a target. The technique used is to slowly move the primary beam bunch outward, using a sawtooth orbit expander as described previously, until the beam particles with large radial oscillations impinge on an outer-radius energy-loss foil. These particles traverse the foil, become phase-unstable, and are lost from the beam bunch. The remaining particles are returned to their normal orbit and are subsequently delivered to either an inner- or outer-radius target. Secondary-particle beam pulses as short as 250 μ sec half-width have been produced by use of this method of trimming the radial width of the primary proton beam.

⁵Walter D. Hartsough, Bevatron Operation and Development. XII, UCRL-3913, Aug. 1957.

ZN-1845

Fig. 7. Top trace: Shaper current perturbed by a sawtooth orbit expander.

Bottom trace: Long-duration secondary-particle-beam pulse produced by slowly expanding the orbit of the primary beam bunch.

Sweep speed 100 msec/cm.

Figures 8 and 9 show a short secondary-particle beam pulse produced as described. The beam was trimmed during the acceleration period from 1 pip 29 to 1 pip 30 (5.7 Bev to 6.1 Bev) by use of a thin foil on a pneumatically operated probe in the south straight section. In this case, the 2×10^{10} protons per pulse lost from the beam bunch in the trimming period (~ 130 msec) spiraled inward onto an inner-radius target in the west straight section, producing an extended secondary-particle beam for a counter experiment. The remaining beam in the phase-stable bunch, 5×10^{10} protons, was delivered at an energy of 6.2 Bev, in a 250- μ sec half-width pulse (using an abrupt rf-turnoff method), to a second target in the west straight section for a bubble chamber experiment.

MAGNET POWER SUPPLY

The shutdown work on the motor-generator sets and associated equipment was completed during the first month of this period. A summary of this work appears in the preceding Bevatron Quarterly Report. On May 21, magnet pulsing was resumed. For a period of 5 days, with the Bevatron vacuum tank at atmospheric pressure, the magnet was pulsed for tests of the generators, for ignitron degassing and high-voltage bake-in, and for other tests as mentioned in a previous section. Following the pumpdown of the Bevatron vacuum tank, the normal schedule of magnet pulsing was resumed. The operating value of magnet voltage, however, was reduced from the preshutdown value of 16.05 kv (Tap 3) to 14.25 kv (Tap 5) in an effort to improve the reliability and life of the ignitrons and therefore to increase the effective beam time. At the end of this quarter, however, there is as yet no evidence of a reduction in time lost owing to ignitron faults. Table II compares the Tap 3 pulsing record during the two months prior to the shutdown with the Tap 5 operation during the last two months of this period. In each case, the figures are averages of normal 7-day-per-week operation; both rectification and inversion faults are included in the averages. The total number of pulses per week, during this period, was less than prior to the shutdown because of a higher fault rate and also because of a reduction in pulse rate necessitated by a longer pulse length at the reduced value of magnet voltage (11 pulses per minute at Tap 3 vs 10 pulses per minute at Tap 5).

This period, immediately following an extended shutdown, must necessarily be considered a recovery period. If, in the future, there occurs a significant reduction in fault rate, it is expected that the number of pulses per week would be the same as or greater than with Tap 3 operation.

During this quarter, four ignitrons failed and were replaced.

The ignitron fault rate is summarized in Table III.

The magnet-pulsing record appears in Table IV.

ZN-1846

Fig. 8. Top trace: South sum induction-electrode signal.
 Bottom trace: Integrated output of a counter telescope
 looking at targets in the west straight section.
 Sweep trigger I-28. Sweep speed 50 msec/cm.
 The spiked beam pulse (250 μ sec half-width) at I-33 was
 produced by trimming the radial width of the primary proton
 beam bunch on an outer-radius foil (130 msec beam spill),
 returning the remaining protons in a bunch to their equilibrium
 orbit, and subsequently causing the bunch to strike an inner-
 radius target by turning the rf off abruptly.

ZN-1847

Fig. 9. Magnified display of the spiked beam pulse in Fig. 8.
 Top trace: I pip 33 (6.2-Bev marker).
 Bottom trace: Integrated output of a counter telescope
 looking at targets in the west straight section.
 Sweep speed 500 μ sec/cm.

Table II

Comparative pulsing record for Tap 3 operation during the two months prior to the shutdown and Tap 5 operation during the last two months of this quarter.

Magnet Voltage Tap	Magnet Voltage (Kv)	Average number of magnet pulses per week	Average number of magnet faults per week*	Average number of pulses per fault
3	16.05	54,021	42	1,277
5	14.25	41,591	62	671

* Both rectification and inversion faults are included.

RESEARCH

The research activity during this quarter is summarized in Table V.

ACKNOWLEDGMENTS

The Bevatron group leader is Edward J. Lofgren, and under him Harry Heard, with Walter Hartsough assisting, is in charge of operations. The Bevatron operators are Robert Anderson, Wendell Olson, and Robert Richter as crew chiefs; G. Stanley Boyle, Gary Burg, Durward Cagle, Norris Cash, Frank Correll, Robert Gisser, William Kendall, Ross Nemetz, Fred Lothrop, Frank Ulbrich, and Glenn White as crew members. Special development projects were carried out by Bruce Cork, Harry Heard, and Emery Zajec. Harold Vogel was the engineer in charge of the motor-generator sets. The mechanical engineering group was headed by William Salsig; the electrical engineering group was headed by Clarence Harris and Marion Jones. Ivan Lutz directed the electronic development group. Lorenzo C. Eggertz was in charge of the electrical maintenance group.

This work was done under the auspices of the U. S. Atomic Energy Commission.

Table III
Ignitron fault rate *

MONTH	5 to 7 pulses per minute						7 to 10 pulses per minute						10 to 17 pulses per minute					
	1500 to 6000 amps			5000 to 8000 amps			1500 to 6000 amps			5000 to 8000 amps			1500 to 6000 amps			6000 to 8000 amps		
	PULSES	FAULTS	P/F	PULSES	FAULTS	P/F	PULSES	FAULTS	P/F	PULSES	FAULTS	P/F	PULSES	FAULTS	P/F	PULSES	FAULTS	P/F
1956																		
Jan	-----	---	---	-----	---	---	-----	---	---	6718	7	960	11148	1	11148	3433	1	3433
Feb.	177	---	---	7468	15	497.6	2922	4	730	38146	95	401	23624	3	7874	6735	15	449
Mar	678	6	113	3208	7	458.2	207	1	207	43782	71	616	30358	9	3373	119065	162	735
Apr	13193	1	13193	26778	43	622	35831	3	11943	31209	57	547	16297	6	2716	16024	17	942
May	165	---	---	3054	1	3054	2062	1	2062	59288	115	515	35595	6	5932	72777	92	790
June	120	---	---	285	---	---	3198	0	---	123197	187	657	17759	16	1109	3070	3	1023
July	-----	---	---	-----	---	---	-----	---	---	90655	131	684	14036	2	7018	90375	83	1088
Aug	-----	---	---	-----	---	---	-----	---	---	7755	7	1107	10938	1	-----	190009	208	913.5
Sept.	-----	---	---	-----	---	---	1677	---	---	12447	10	1245	6278	1	-----	95784	71	1346
Oct	-----	---	---	-----	---	---	-----	---	---	59320	4	14830	-----	---	-----	144463	111	1301.5
Nov	-----	---	---	-----	---	---	174	---	---	11496	12	958	82523	4	20630	147582	102	1446.8
Dec	467	---	---	2560	2	1280	355	---	---	39394	15	26263	7987	4	1997	36367	44	825.3
1957																		
Jan	1456	---	---	5882	15	392	2680	---	---	29639	32	926	29157	2	14578	117745	113	1042
Feb.			NO	OPERATION			Shutdown for Maintenance and Overhaul											
Mar.			"	"			"	"	"	"	"	"						
Apr.			"	"			"	"	"	"	"	"						
May			"	"			"	"	"	"	"	"						
June	1144	---	1144	12799	23	550	1744	1	1744	36648	80	458	17929	9	1992			
July	72	---	72	5012	11	456	1372	2	686	48854	70	6979	33027	35	945	106896	124	878

* Refer to previous Quarterly Reports for information on 1954 and 1955 fault rates.

MUB-166

Table IV
Magnet-pulsing record, October 1954 through July 1957

Month	Number of Pulses	Number of Faults	P/F	Month	Number of Pulses	Number of Faults	P/F
1954				1956			
Oct.	112,361	247	454.9	Jan.	21,299	9	2,366.6
Nov.	78,348	366	214.1	Feb.	79,072	132	599.0
Dec.	58,693	193	304.1	Mar.	197,298	256	770.7
1955				Apr.	139,332	127	1,097.1
Jan.	109,381	296	369.5	May	172,876	215	804.1
Feb.	89,503	250	358.0	June	147,629	206	716.6
Mar.	118,135	170	694.9	July	195,066	216	903.1
Apr.	149,753	104	1,439.9	Aug.	208,702	216	966.2
May	152,739	229	667.0	Sept.	116,186	82	1,417
June	163,500	29	5,637.9	Oct.	203,783	115	1,772
July	164,210	57	2,880.9	Nov.	241,775	118	2,049
Aug.	144,391	84	718.9	Dec.	87,130	65	1,340
Sept.	78,494	54	1,453.6	1957			
Oct.	124,653	145	859.7	Jan.	186,559	162	1,164
Nov.	143,646	172	835.2	Feb.	No operation. Shutdown		
Dec.	118,014	145	813.9	Mar.	"	"	"
				Apr.	"	"	"
				May	"	"	"
				June	70,264	117	562
				July	195,233	247	707

Table V

Bevatron experimental research program May, June, July 1957		
INTERNAL GROUPS		
<u>Group</u>	<u>Experimenters</u>	<u>Experiments</u>
ALVAREZ		
	Gow, Ticho	Interactions of 1.12-Bev/c negative particles in hydrogen using the 10-inch liquid hydrogen bubble chamber. Search for asymmetries in the production and decay of $\pi^- + p \rightarrow \Lambda + K$, $\Sigma + K$ and $K^- + p \rightarrow \lambda + \pi$, $\Sigma + \pi^0$. Also a search for $K^- + p \rightarrow \Xi^0 + K^0$.
	Gottstein	Emulsion exposure to unseparated 400-Mev/c K^- mesons (3 stacks)
BIRGE		
	Birge, Lanou, Whitehead	Decay and interactions of K^0 mesons produced by charge exchange in a cloud chamber. The momentum of the incident K^+ meson beam was 550 Mev/c.
MOYER		
	Osher, Parker	π^0 modes of heavy-meson and hyperon decay, using counters.
	Hess, Patterson, Wallace	Measurement of the attenuation mean free path in concrete of high-energy neutrons. Total cross-section measurements for 5-Bev neutrons on Pb, CH_2 , and C.
SEABORG		
	Alexander	U, Al foil bombardment (6.2 Bev)
	Benioff	$(COOH)_2$, $(CH_2)_n$, Al target bombardment (5.7 Bev)
	Caretto	CN_5H_3 , Al target bombardment (5.7) Ag, 5U , Mylar target bombardments (2) (6.0 Bev) Cu, Mylar target bombardments (2) (6.0 Bev)

INTERNAL GROUPS

Group:

Experimenters

Carnahan

Crosby, Winsberg

Ladenbauer

Experiments

U, Al foil bombardments (3) (5.7 Bev)

Al, Au foil bombardment (6.2 Bev)

Iodoform, cellulose acetate target bombardments (2) (6.2 Bev)

EXTERNAL GROUPS

Institution

Experimenters

Bristol, England

Bohmik, Prowse

Rochester University

Hoang

University of Chicago

Levi-Setti, Telegdi

University of Washington

Lord

Columbia University

Orear

University of Wisconsin

Schneps

Experiments

Emulsion exposure in a focused and separated 420-Mev/c K^- -meson beam.

Emulsion exposure in a focused and separated 550-Mev/c K^+ -meson beam.

Emulsion exposure in a focused and separated 550-Mev/c K^- -meson beam.

Emulsion exposure to unseparated 400-Mev/c K^- mesons. Emulsion exposure to 550-Mev/c K^+ mesons. Asymmetry in μ -e decay from $K_{\mu 2}$

Emulsion exposures (2) to the internal 4.1-Bev proton beam.

Emulsion exposures (2) to 550-Mev/c K^+ mesons. Asymmetry in μ -e decay from $K_{\mu 2}$

Emulsion exposure to an unseparated 400-Mev/c K^- meson beam.

EXTERNAL GROUPS

Institution

Experimenters

Experiments

UCRL Livermore

White

Emulsion exposure to a focused and separated 625-Mev/c K^- -meson beam.

Brookhaven National Laboratory

Zorn

Emulsion exposure to unseparated 500-Mev/c K^- mesons. Emulsion exposure to focused and separated 700-Mev/c K^+ mesons.

The following emulsion exposures were made in a focused and separated 625-Mev/c K^+ beam:

Saclay, France

Berthelot

University of Miami

Blau, Perlmutter

Padova, Italy

Dallaporta

University of Chicago

Haskin, Schein

Bristol, England

Prowse

UCLA

Stork

Brookhaven National Laboratory

Zorn