CERN - EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Presented at the
All Union Seminar on
Physics Data Processing
Yerevan (USSR), 9-16 September 1977

CERN/EF/BEAM 77-2
(CERN/DD 77-13)
5 September 1977

ON-LINE DATA HANDLING FOR A 150 m^2 MULTIWIRE PROPORTIONAL CHAMBER ARRAY

THE EMI FOR BEBC

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ABSTRACT

Muons from interactions in the Big European Bubble Chamber (BEBC) are identified by a 6 x 25 m^2 array of multiwire proportional chambers. The physics requirements posed some special problems for the on-line handling of data from these chambers. In addition, the use of the system as a facility for many experiments dictates a high level of automation of monitoring and testing. This has been achieved under the control of the on-line computer employing a conversational interaction with the user.

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1. INTRODUCTION

The External Muon Identifier (EMI) is a large array of Multiwire Proportional Chambers positioned closely behind the Big European Bubble Chamber (BEBC) at the 400 GeV/c SPS accelerator of CERN. This paper deals with the on-line data handling aspects of EMI. Many of the associated problems are common to other experiments and arise from the size and complexity of apparatus for very high energy physics and from the long periods of reliable running required for statistically valid results. Others are specific to the use of such apparatus in conjunction with a bubble chamber.

2. PRINCIPLE OF THE EMI

Before discussing these problems it is necessary to explain briefly the purpose of the EMI. Its construction has already been described in detail in [1]. In bubble chamber experiments at very high incident particle energies, a problem exists in identifying the outgoing secondary particles from an interaction. When their momenta exceed a few GeV/c they can no longer be distinguished by the visual characteristics of their tracks. When the incident particles are neutrinos, there is special interest in knowing which particles are muons. Muons, unlike the other particles (hadrons), do not interact strongly with matter. The EMI achieves this identification on the principle illustrated in fig. 1. A layer of iron 0.5 to 1.5 m thick is placed behind the bubble chamber. Hadrons entering the iron interact strongly and are absorbed, while muons pass through. A detector placed behind the iron will thus see only the muons. If their positions are recorded on magnetic tape, correlation with measured tracks in the bubble chamber will identify those which are muons.

3. BASIC PHYSICS REQUIREMENTS FOR EMI CHAMBERS AND READOUT SYSTEM

In order to cover a large solid angle the arrangement shown in fig. 2 was adopted. The total detector area is approximately 150 m^2 made up of 3 x 1 m^2 multiwire proportional chamber modules. These contain about 90 000 wires grouped into 18 000 electronic channels to give the necessary resolution of ± 0.5 cm in the central region and ± 3.0 cm at the outside. The inner plane of 6 modules is used to help in the off-line treatment of background. The scale of the finished apparatus may be judged from the photo, fig. 3. The wires in each chamber module are arranged as shown in fig. 4. The primary position information comes from the anode planes at $\pm 30^{\circ}$, while the cathode strips help to remove multi-particle ambiguities.

There were three basic requirements for the readout system, the first two being rather specific to the association with the bubble chamber and the third more general:

(a) The times of interactions during the 2-3 millisecond beam spill are unknown and so, to give positive identification decisions, the EMI had to have very high detection efficiency (> 99%) and no dead time.

(b) A high background of muons is present in the beam (several hundred per spill) and so the EMI had to be capable of separating and registering at least this number of events with no restriction on the number of hits per event. It had also to be self-triggered.

(c) Good time resolution was needed for identifying the interesting rare cases of more than one secondary muon and for dealing with the showers of background particles resulting from neutrino interactions close to the EMI in the iron absorber.

In view of these requirements, direct readout of each hit to computer memory was obviously too slow. A special buffer memory was thus designed allowing the independent read-in of all channels of the EMI in parallel followed by sequential readout after the spill. As shown in fig. 5 it is organised on two levels to reduce the amount of "zero" information stored. Each chamber module has a buffer with one input per channel and space for 39 events (79 in high intensity regions) plus one transfer location for readout. The main buffer has one input per chamber and space for 1023 events on the whole EMI. The buffers consist of MOS shift registers whose contents advance each time an event is recorded. For a given event the chamber buffers record the pattern of wires hit in the affected chambers while the main buffer records the pattern of chambers hit. The input logic ensures that no hits are missed at the expense of some overlap of events close in time. Readout is handled by a CAMAC interfaced control unit. This sequentially scans the event entries in the main buffer. For each entry it addresses the chambers seen to have been hit and outputs the numbers of the channels involved. Fig. 6 shows the format of this output. Chambers and event entries are identified by number and word counts inserted to facilitate later access to the information.

4. OPERATIONAL REQUIREMENTS

Beyond these basic needs for physics there were several operational requirements which shaped the overall aspect of the hardware and on-line software:

(a) The detector consists essentially of a single plane of chambers and is self-triggering. Testing with data from the beam is thus almost impossible. Separate tests, both digital and using cosmic rays, are necessary and must proceed during the 8.4 second interval between beam spills.

(b) The EMI should operate reliably over several years serving many teams of physicists, most of whom will have little chance to become familiar with the apparatus. Thus, the operation and testing had to be made as automatic as possible with good protection against mishandling.

Point (a) is covered by several hardware and software features. Fig. 7 shows the sequencing for taking data synchronised with the beam. A warning pre-pulse allows the computer to initialise the EMI. Then a beam timing pulse from the accelerator generates a gate to allow data to be taken. Readout starts automatically when the gate closes and proceeds as a series of direct block transfers to computer memory. The test features involve selections of sub-sets of chambers to test and alternative ways of generating the external gate. They are summarised in Fig. 8 parts 2-5. In the first (8.2) the computer simply emulates the external gate and data are collected from cosmic rays. In practice, cosmic ray tests are usually done on one chamber at a time to limit the histogramming space needed in the computer to a reasonable amount. In this case, data can be collected more efficiently using the method of 8.3, where the gate does not close until the chamber buffer is full. The remaining two modes are digital tests of the electronics. In 8.4, the cathode of the desired chamber is pulsed to induce signals in all channels and the computer verifies the resultant readout pattern. In 8.5, the computer introduces artificial data into the main buffer.

The tests are run using the strategy illustrated in fig. 9. The data taking proceeds in two "streams". Stream 1 takes data synchronised with the beam spill. As soon as the processing of this data is complete, the computer switches the conditions or "context" of the EMI to those required for testing (stream 2) and as many cycles of test data taking as possible are carried out before the next spill arrives. To avoid wasting time starting cycles which have to be aborted before they are complete, no stream 2 cycle is allowed to start later than 6.5 seconds after the last spill.

The automation of the system to cover point (b) has been achieved by placing it under the control of the on-line computer as shown in fig. 10. All interfacing to the computer is carried out in CAMAC. Power supply levels, gas mixture flows to the chambers and reference voltages are surveyed by a computer-controlled monitoring system using a reed relay switching network. In all some 640 values are checked. There are also three alarm inputs for immediate attention. These signal a tripping of the hydrogen safety interlocks, overcurrent in the high tension supplies (indicating a discharge in a chamber) and over-temperature in the buffer memory crates. Other information received by the computer includes the frame numbers of the bubble chamber, the time of day which is used to correlate all activities in the neutrino beam zone, and beam intensity information from the beam-monitoring computer. Some input and output registers allow the computer to set triggers and enabling levels and to verify the presence of external timing signals.

5. COMPUTER CONFIGURATION

The NORD-10 computer is shown in more detail in fig. 11. The configuration is rather large in view of the variety of tasks to be performed. It has 64 kW of core memory with a memory management system allowing relocation of 1 kW pages. This is supported by a 10 Mbyte disc. The experimenter operates the EMI from a user station centred on a Tektronix 4010 graphics terminal. Here he gives commands and receives responses, status information and plots of test results. He may print information on one of two printers and also make direct paper copies of plots on the display. Basic information and error warnings are displayed on the warning panel whose large characters are visible at a distance and which is equipped with an audible alarm to attract attention. A strip printer keeps a log of all starts, stops and errors. There is also provision for several terminals for program development and bookkeeping.

6. SOFTWARE

The support of programs to run all this equipment requires a rather sophisticated software operating system. This requirement is met by SINTRAN III supplied by the computer manufacturer. SINTRAN III schedules the running of programs according to priority, looks after queuing for resources and uses the paging system and disc to implement a virtual memory scheme in which only those parts of programs required for execution are in core memory. The memory spaces of programs are mutually protected. The system also allows time-sharing background activities such as program development to be carried out while the EMI is operating.

It was recognised that, although such an operating system provides very comprehensive facilities, controlling programs by keyboard commands to the system is not simple and involves the learning of many complex operating procedures not of immediate interest to the experimenter. The EMI software was thus designed as a self-contained package initialised by push-button. All user dialogue is handled within this package and the component programs are activated by commands having direct relevance to the application.

Two main design decisions were associated with data output to magnetic tape. How much data reduction should be attempted and what should be the tape format? It was decided that all original data should appear on tape and so no attempt was made at pre-analysis (e.g. point reconstruction). Reduction was restricted to formal compression by grouping consecutive channels hit into clusters. This led to a space saving of about 30%. The tape format was decided on in collaboration with other groups at CERN [2] and is illustrated in fig. 12. It is based on a fixed physical record length of 1890 16-bit words. This gives good tape utilisation, easily estimated tape length used and ease of reading as a whole number of words on machines with a wide variety of word lengths. The logical records (e.g. the EMI data from one spill) are entirely decoupled from the physical ones and are accessed by a system of pointers and word counts.

Each aspect of the EMI is controlled by one or more independent programs or tasks. These communicate with each other and have access to common data buffers via a SINTRAN III construct which allows them to share a segment of virtual memory space. The set of programs is shown in simplified form in fig. 13. Except for some specialised code in an intermediate level language (N-PL) they are all written in FORTRAN.

The largest is that for user interaction. Commands consist of two-character mnemonics and a numeric parameter. If in doubt, the user can display a list of commands or select the appropriate parameter from a menu for each command. Specialised parameters for the selected command are then entered conversationally. Separate sets of conditions are maintained for the two streams and the command handler may be set to act on either. Graphics output is done as an overlay to save virtual memory space. Figs 14-17 show examples of output copied from the display. The first is the standard run status output. Stream 1 is writing data on tape while stream 2 is passive but ready to run a cosmic ray test in chamber # 8. The next is a plot of channels hit in chamber #38 exposed to cosmic rays. The form is due to the chamber geometry. 16 and 17 show respectively the time and space distribution of the wide-band neutrino beam as seen by the EMI chambers.

The actual data acquisition from the EMI is done by a chain of tasks triggered by various external interrupts, or by the interaction task in the case of tests. The chain uses conditions for stream 1 or stream 2 as appropriate. If the first task, that for EMI initialisation, is triggered by the beam pre-pulse, stream 1 is set, if by the interaction task or re-cycle code, stream 2 is set. The sequencing of the readout and writing to tape takes place as already described. Only the stream 1 data is written to tape and has added to it the frame number, time and neutrino beam intensity information. After the readout phase, optional checks are applied to the data at selectable levels down to a detailed analysis of each word (extra checks are made in digital test modes). At this stage, data can also be passed to a set of programs running in sampling mode which provide printed dumps of data and graphical representations of individual events in chambers. Next, according to the tests selected, the data are scanned to update histograms such as the wire maps, event times and hit rates in chambers. When a histogram has the desired amount of data, the test is switched off and the user informed. Lastly the stream control logic decides if a stream 2 cycle is to be started.

The other major sub-system is that looking after the voltage monitoring. It sequentially selects values to be measured each second and compares them with declared limits, giving warnings of discrepancies.

All errors detected in the system are passed to the error reporting code and output in standard format on the warning display and log printer.

7. DATA BASE FILES

The software maintains four data base files on disc. The first contains the chamber channel number definitions and a list of channels known to be bad (dead and noisy). The user may update and retrieve this list and it is referred to automatically during cosmic ray testing to decide if a warning should be given of a new bad channel. The second is a chamber performance log holding recent values for efficiency etc. The third forms the classified list of points and limits for monitoring. The last contains a log of monitored values. Entries are made in this whenever the value read changes by more than a specified amount with respect to the last. It is useful for analysis of impending failure.

8. OPERATIONAL EXPERIENCE

The EMI has operated with BEBC since January 1977, first of all in a narrow-band beam of low intensity and more recently with a wide-band beam whose background levels are approaching the EMI design limits. About 150 data tapes have been written, associated with 430 000 bubble chamber pictures. The wide-band beam gives 250-300 events spill on the EMI resulting in 4-5000 words read into the NORD-10 and 3-4000 written on tape. This takes about 1 second. Full checking on this data uses another 2-4 seconds and since this implies that stream 2 tests will run slowly, the checking code is being optimised. Operational reliability has been very satisfactory and the narrow-band experiments [3] estimate to have good EMI data for 95% of their 345 000 pictures. In these, the overall EMI efficiency is above 98%. Visiting physicists seem capable of operating the equipment after 3 or 4 training shifts and it is possible that this could be improved by a more formal approach to instruction. It is expected that from time to time small additional detector arrays will be added to BEBC for specific experiments and read out via the EMI system. The first such experiment is already in operation and its data acquisition has proved simple to interface to the EMI software as an independent set of tasks activated from a small number of hooks in the main chain. From the start, the software has undergone rapid evolution and the ability to continue with development and carry out modifications while running has been most useful. The rate of modification is now decreasing and it is expected that the system will be virtually stabilised by the end of this year.

Acknowledgements

We gratefully acknowledge the continual collaboration of the rest of the EMI construction team: C. Brand, R.C.A. Brown, A. Gilgrass, H.J. Hilke, P. Lazeyras and R. Wigmans. Thanks are also due for the support and encouragement of Dr. A. Minten and Prof. C. Peyrou and to Dr. A. Grant for many valuable discussions on the realization of the EMI project.

REFERENCES

[1] C. Brand et al., Nuclear Instr.and Methods 136 (1976) 485.

[2] J. Ogilvie, Nord Information Notes, CERN EP Division, ND 77-1/1.

[3] P.C. Bosetti et al., submitted to Phys. Letters B, CERN/EP/PHYS 77-37 (1977).

PRINCIPLE OF EXTERNAL MUON INDICATOR (EMI).

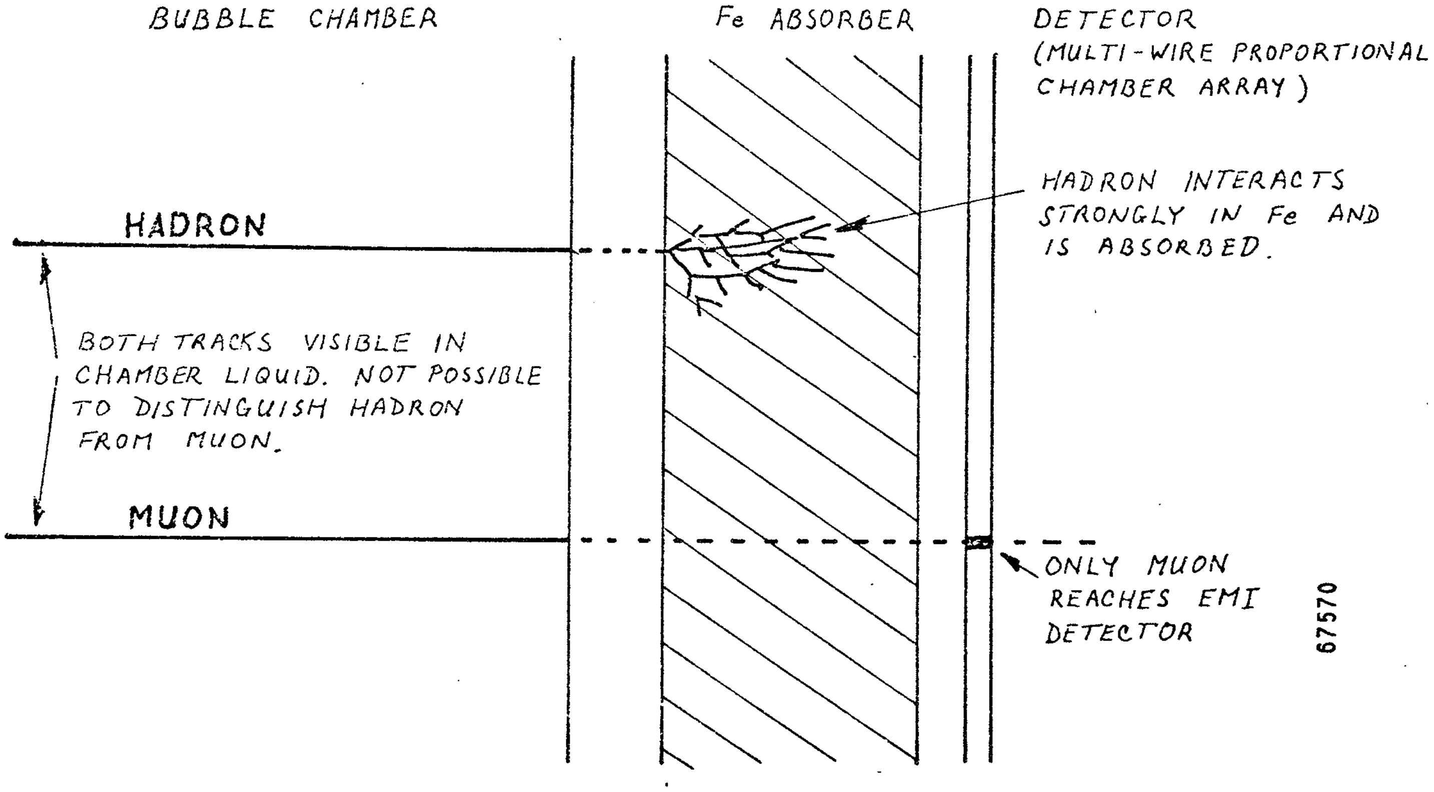

Figure 1.

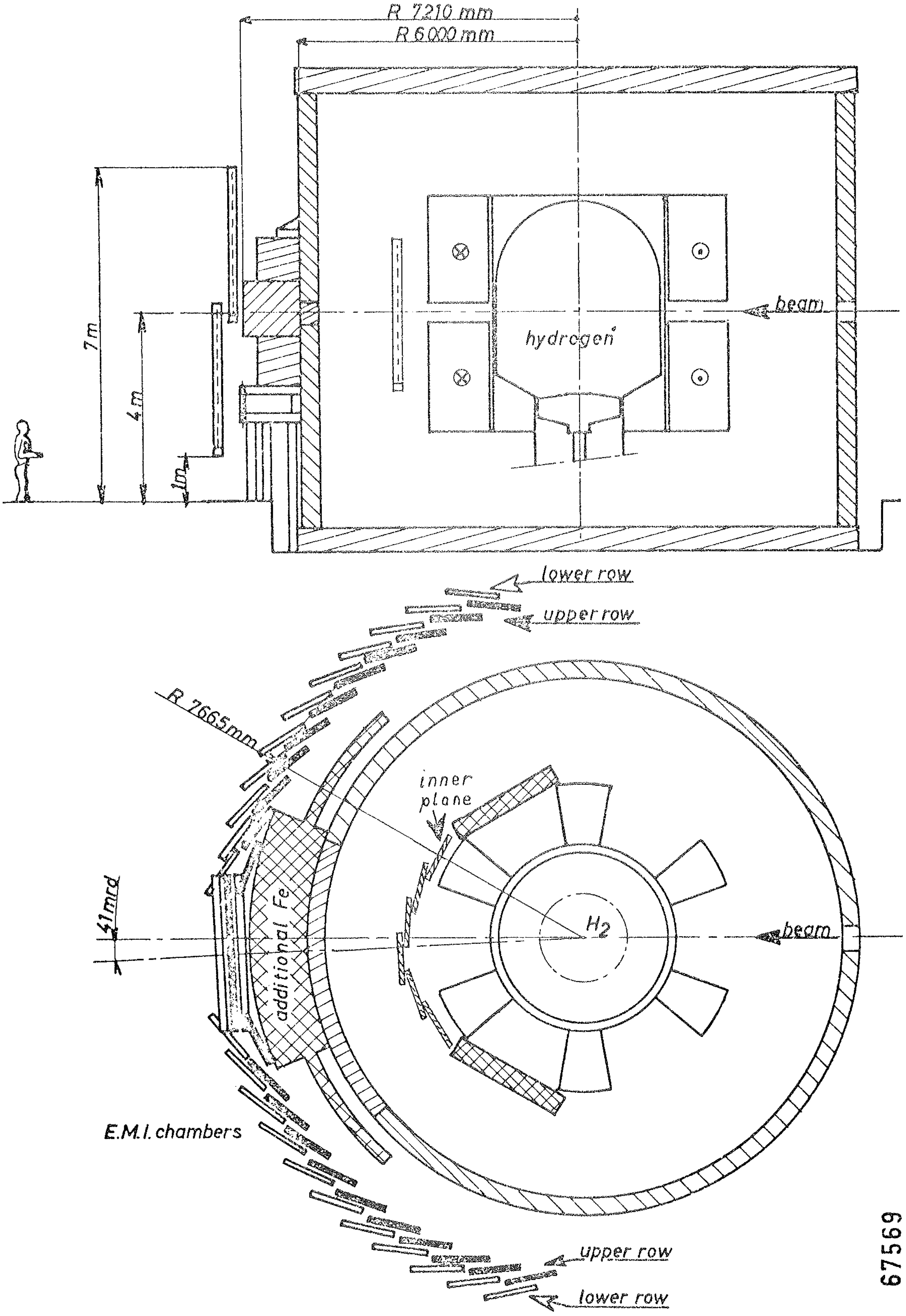

Figure 2. General arrangement of EMI chambers.

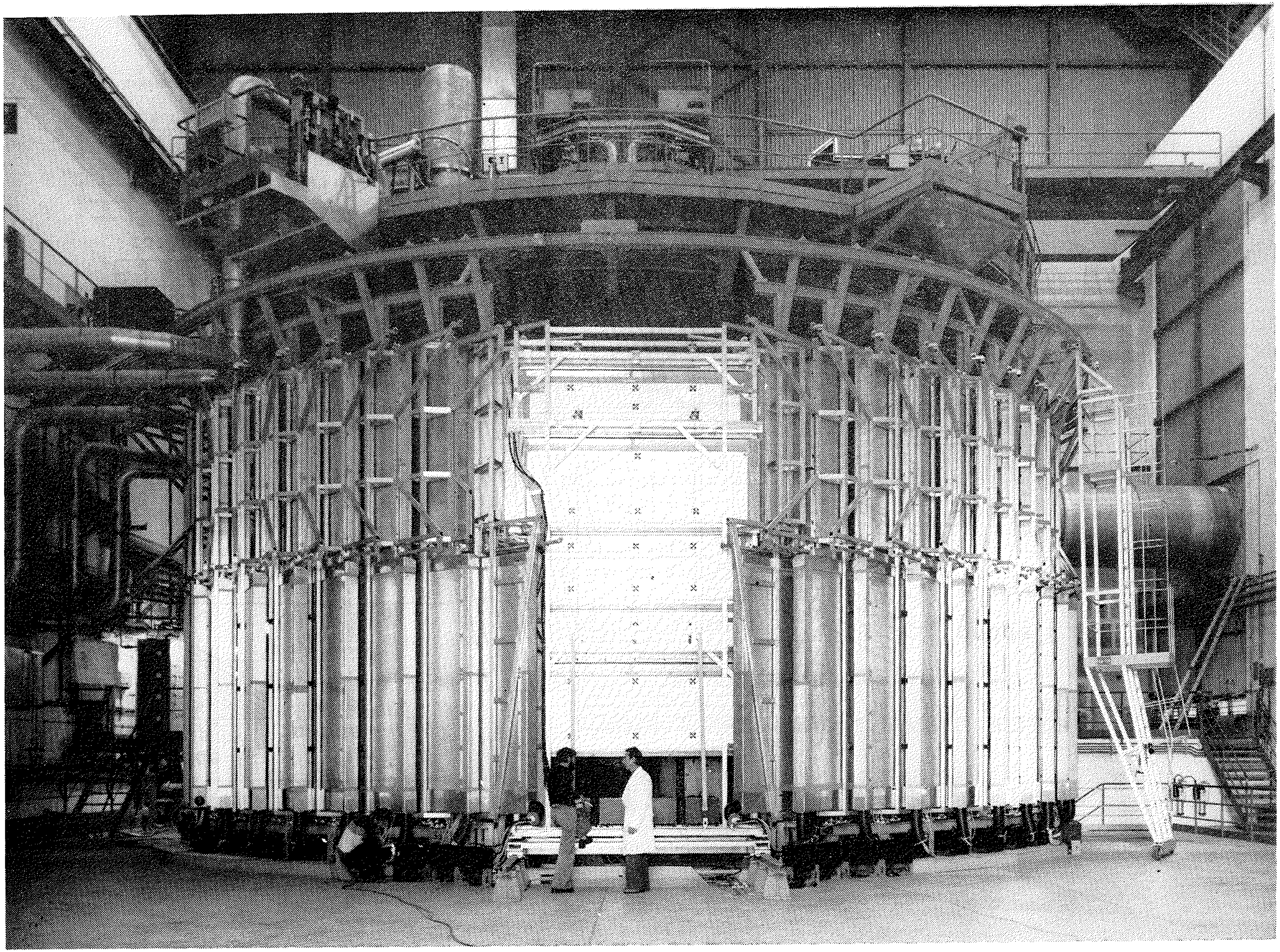

Figure 3. The External Muon Identifier of BEBC.

EMI DATA STREAM

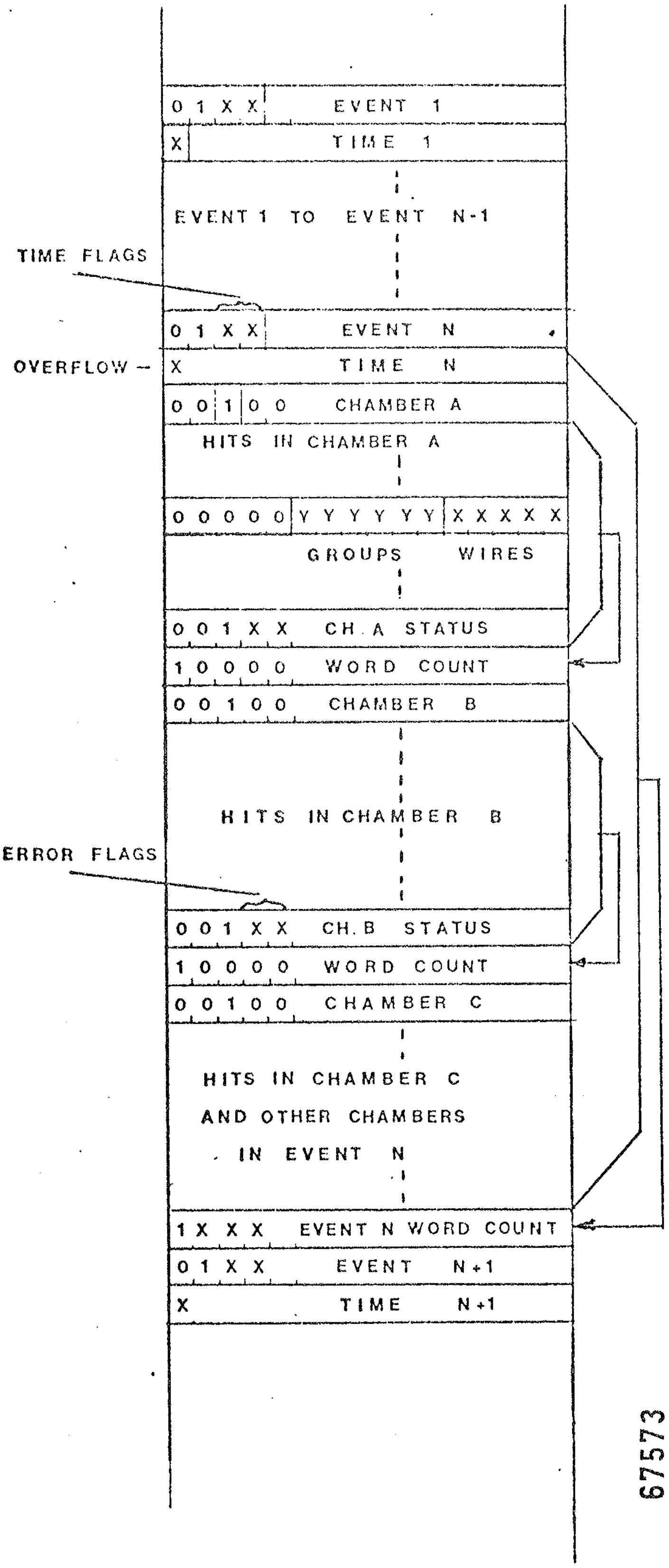

Figure 6.

EMI SEQUENCING

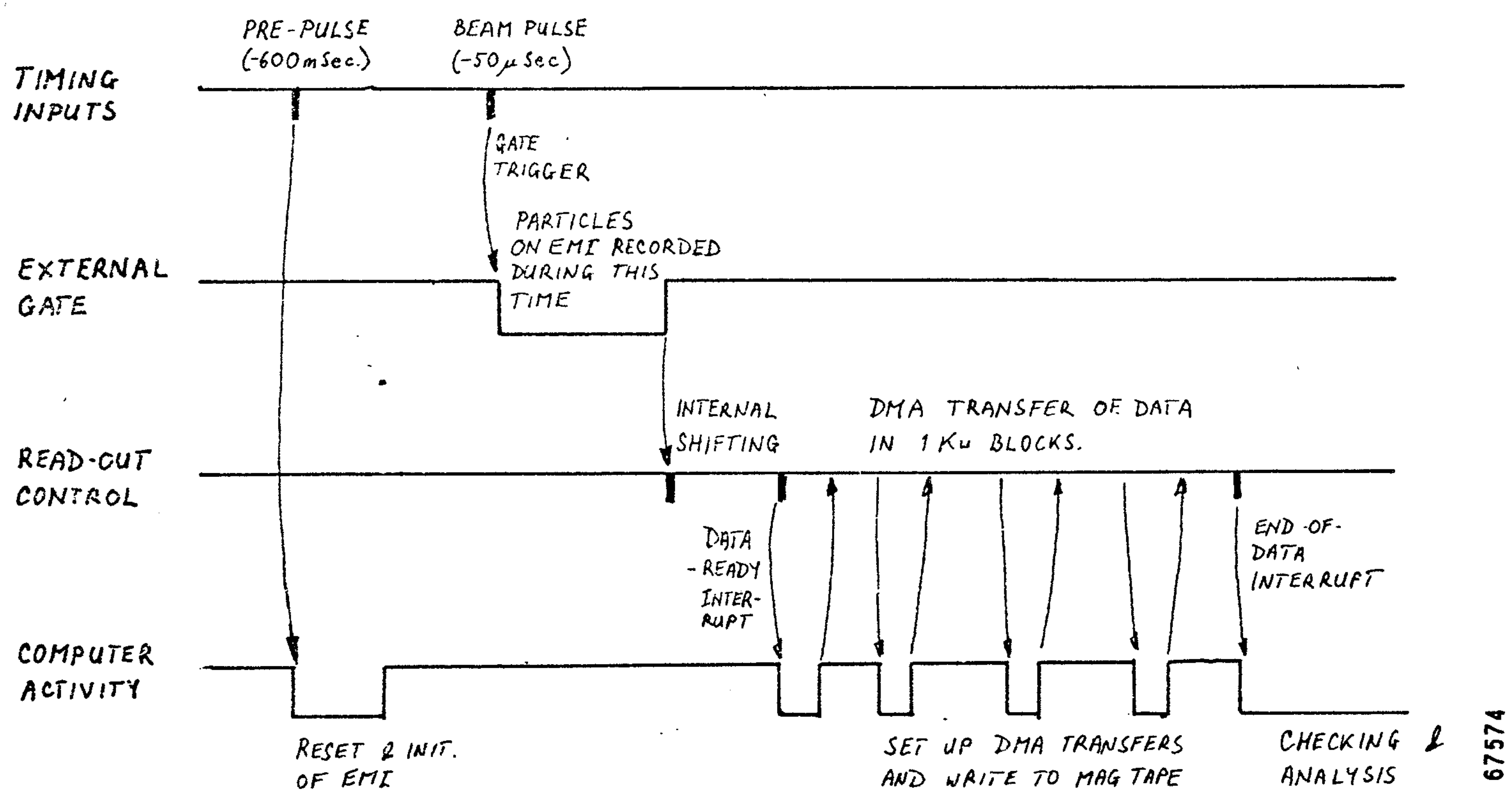

Figure 7.

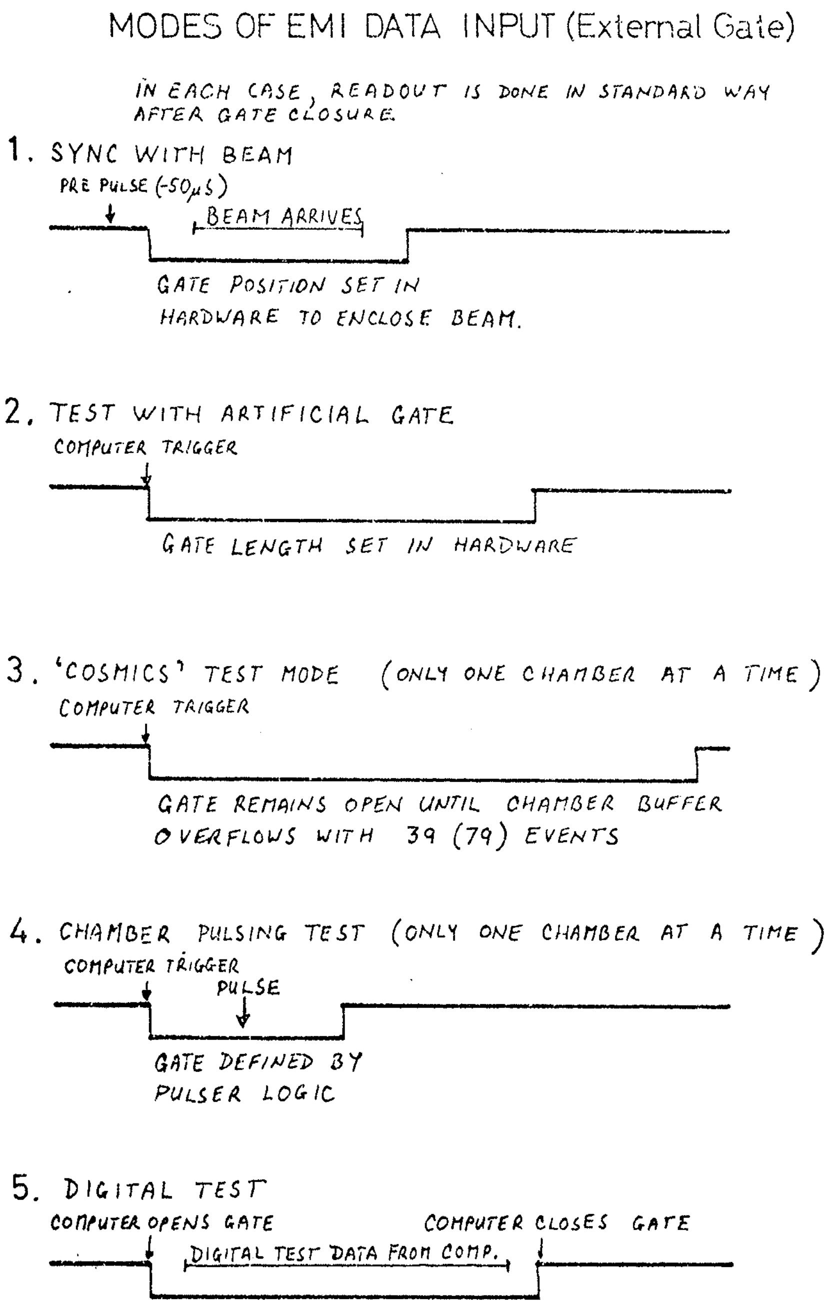

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Figure 8.

EMI CYCLING IN 2-STREAM MODE
(1=Beam data, 2=Tests)

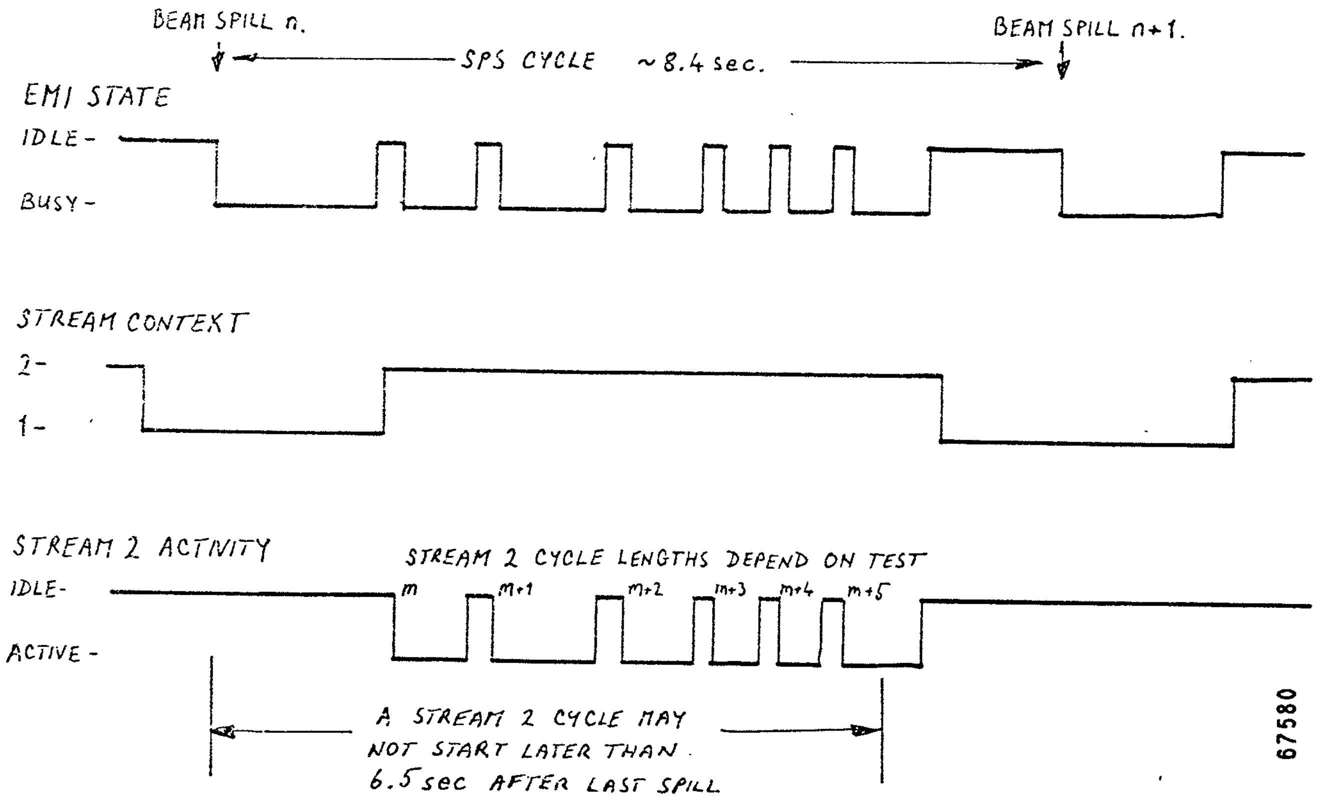


Figure 9.

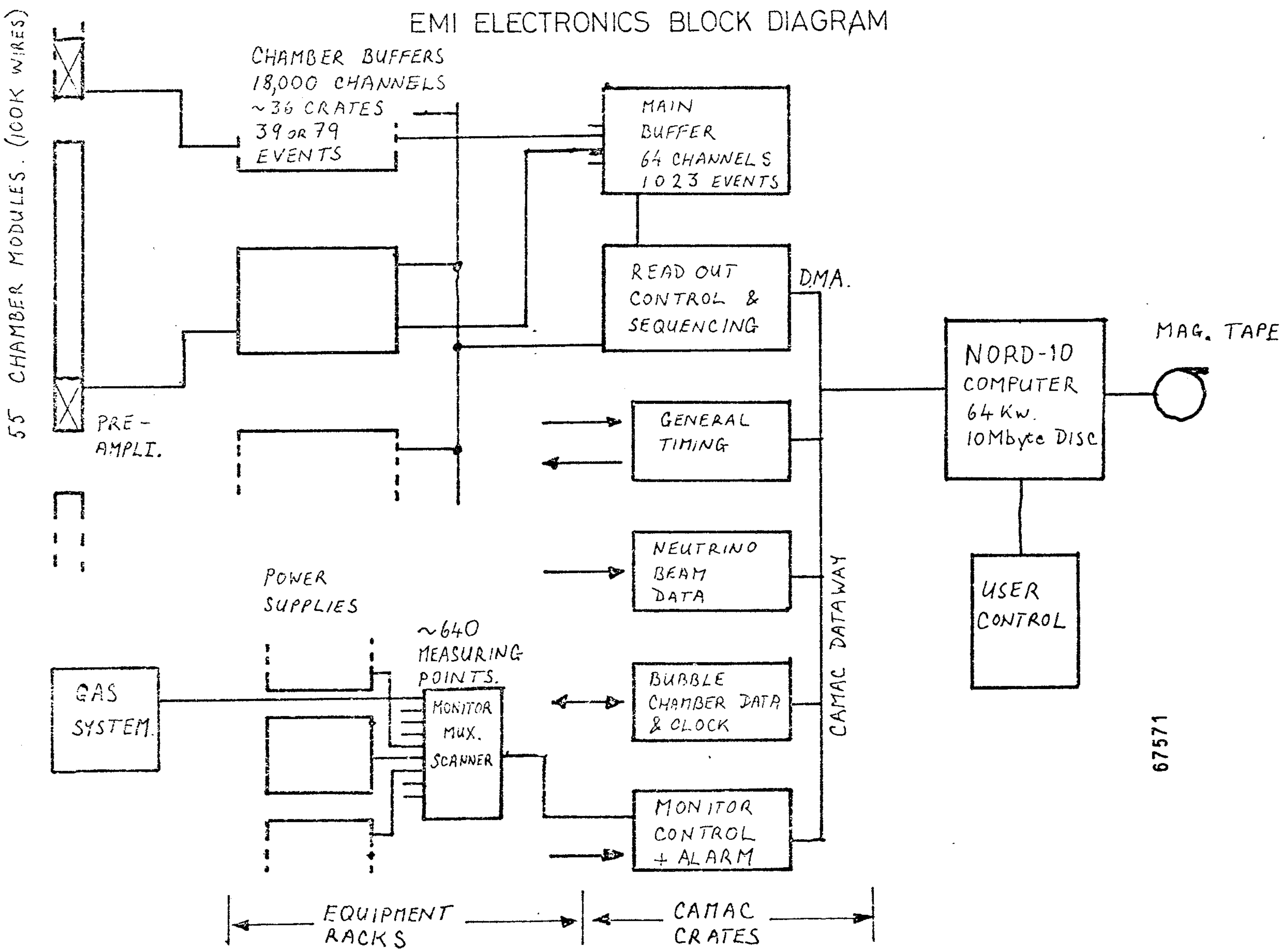

EMI ELECTRONICS BLOCK DIAGRAM
55 CHAMBER MODULES. (100K WIRES)
PRE-AMPLI.
CHAMBER BUFFERS
18,000 CHANNELS
~36 CRATES
39 OR 79
EVENTS
MAIN
BUFFER
64 CHANNELS
1023 EVENTS
READ OUT
CONTROL &
SEQUENCING
DMA.
GENERAL
TIMING
NEUTRINO
BEAM
DATA
BUBBLE
CHAMBER DATA
& CLOCK
MONITOR
CONTROL
+ ALARM
CAMAC DATAWAY
NORD-10
COMPUTER
64 Kw.
10Mbyte DISC
MAG. TAPE
USER
CONTROL
POWER
SUPPLIES
~640
MEASURING
POINTS.
MONITOR
MUX.
SCANNER
GAS
SYSTEM.
EQUIPMENT
RACKS
CAMAC
CRATES
67571

Figure 10.

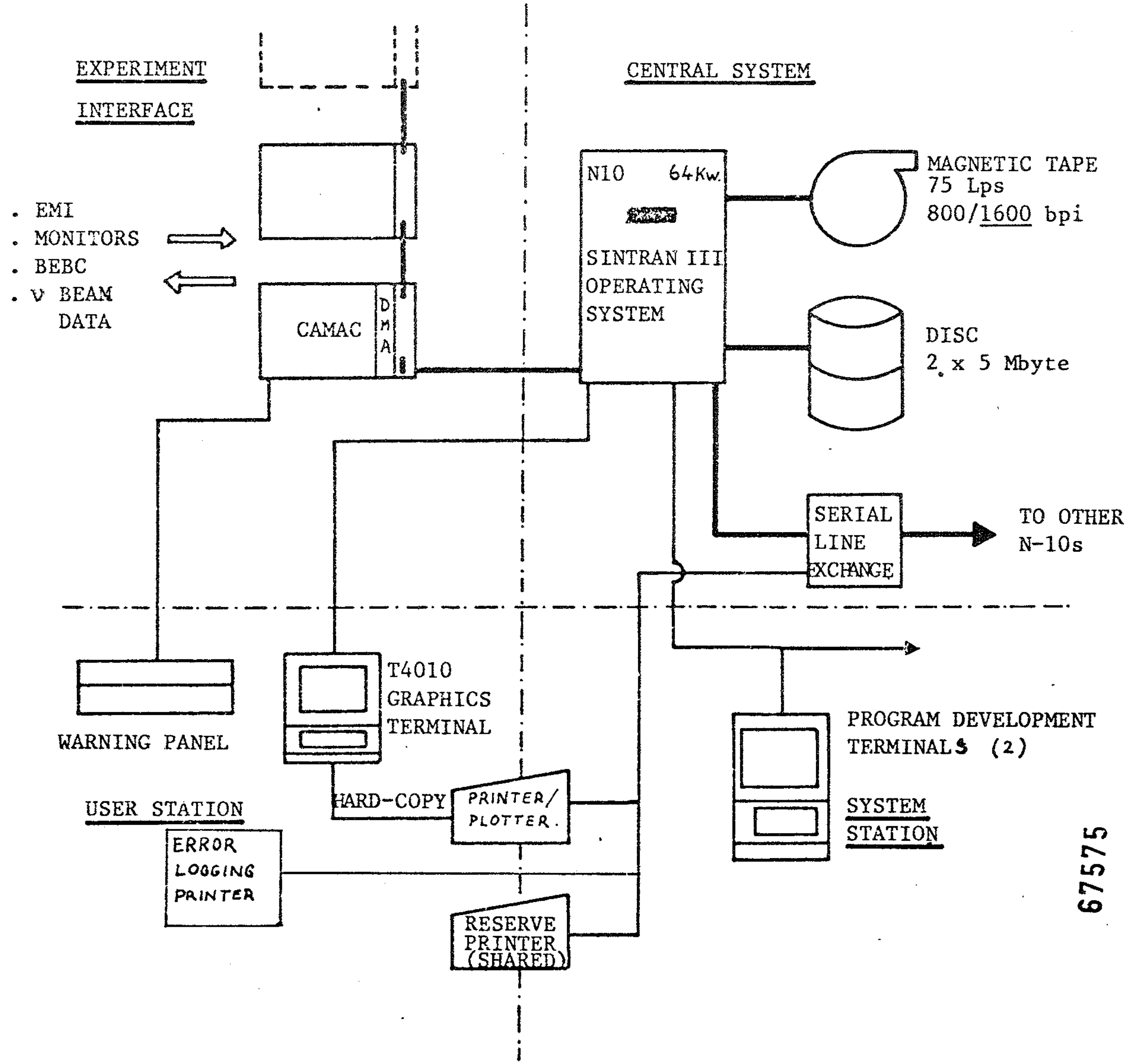
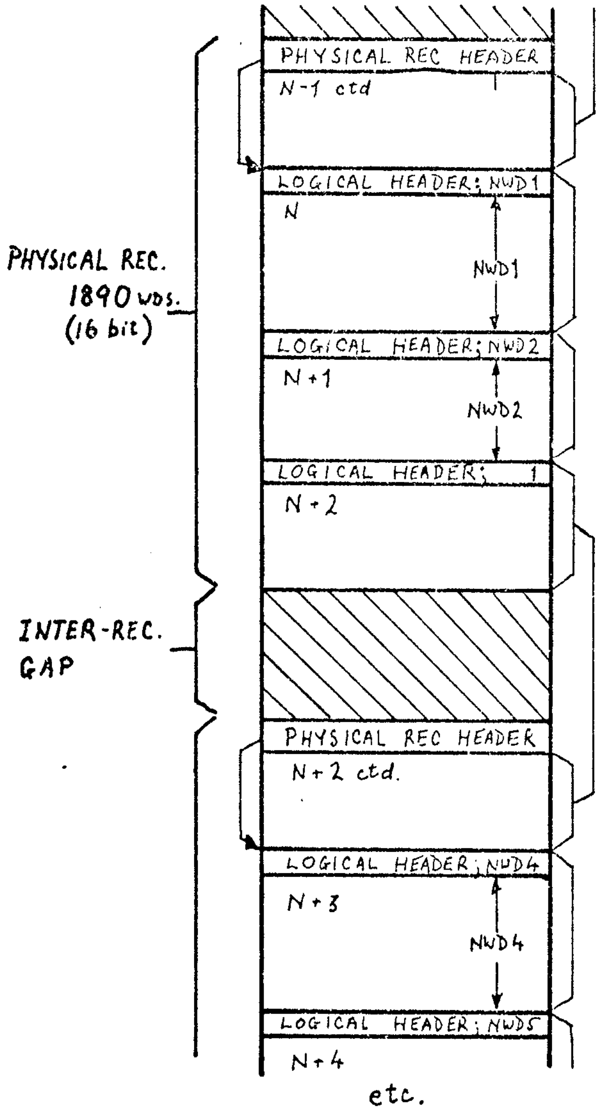


Figure 11. The on-line computer system for BEBC EMI

EMI MAGTAPE FORMAT.



LOGICAL REC.TYPES

- EMI CHAMBER DATA
- EMI SYSTEM STATUS
- USER COMMENTS
- EMI TEST SUMMARIES
- MONITOR SUMMARIES

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Figure 12.

EMI ONLINE SOFTWARE

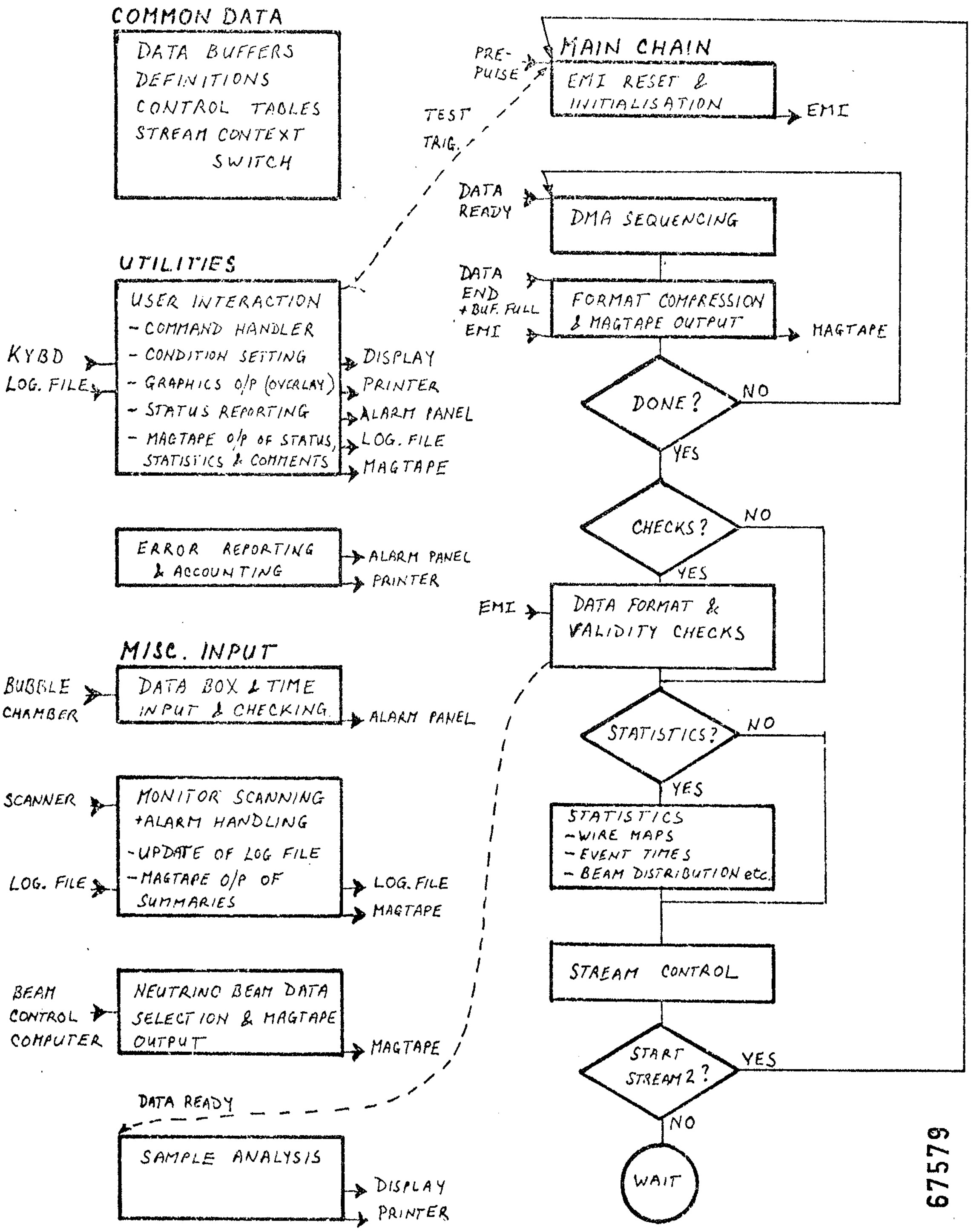
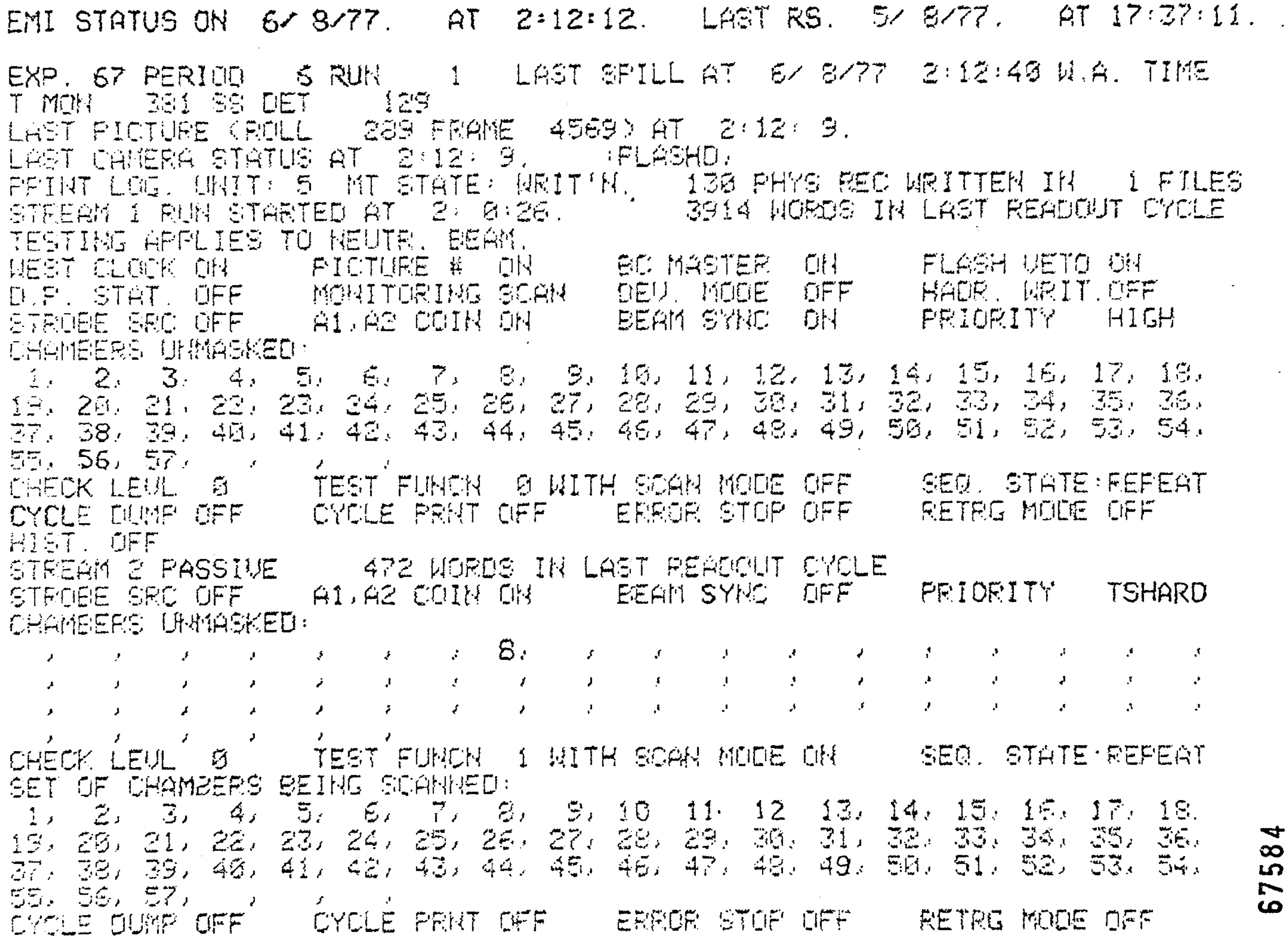


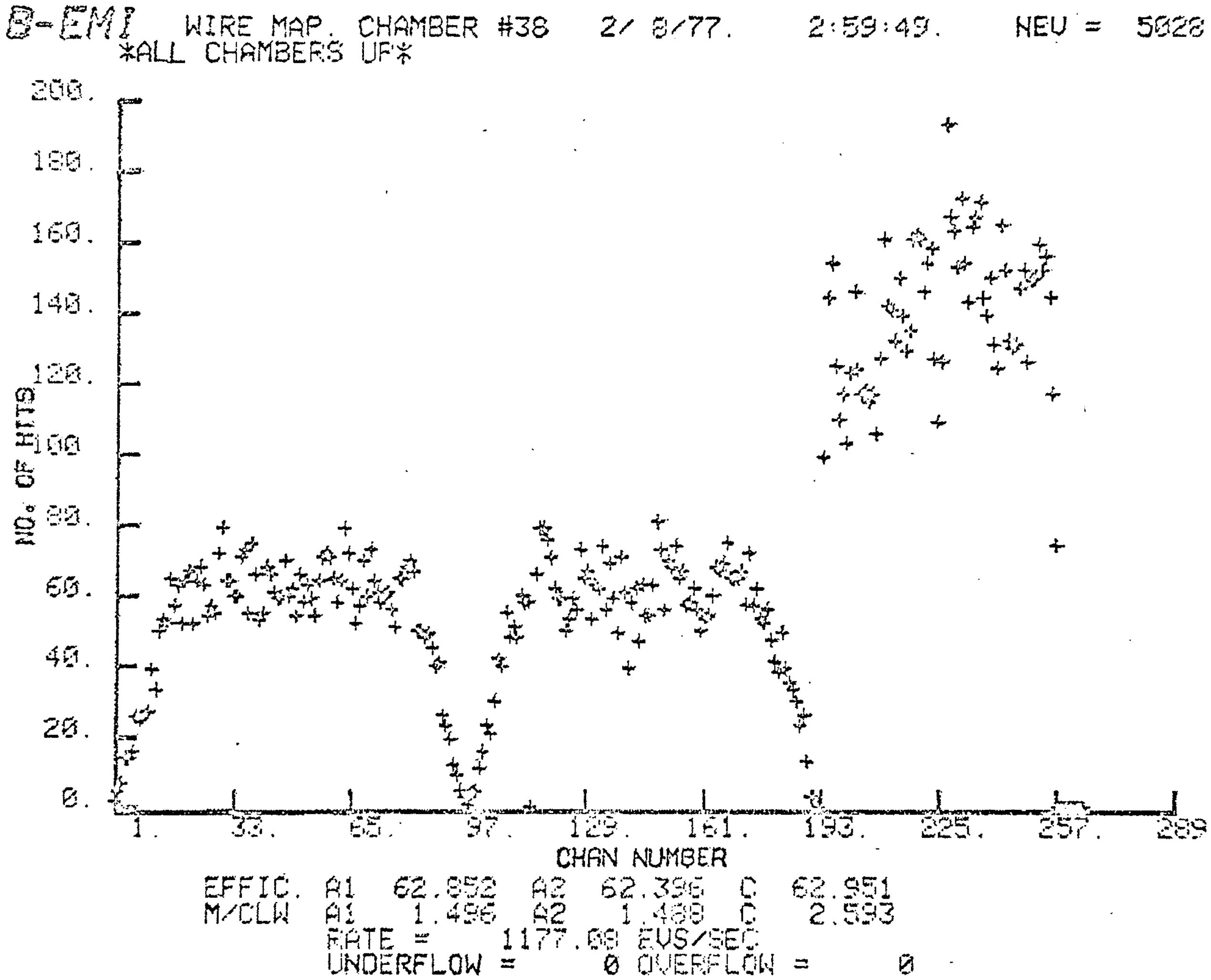
Figure 13.



```
EMI STATUS ON  6/ 8/77.   AT  2:12:12.   LAST RS.  5/ 8/77.   AT 17:37:11.

EXP. 67 PERIOD   5 RUN    1   LAST SPILL AT  6/ 8/77  2:12:40 W.A. TIME
T MON   381 SS DET    129
LAST PICTURE (ROLL   289 FRAME  4569) AT  2:12: 9.
LAST CAMERA STATUS AT  2:12: 9.    :FLASHD,
PRINT LOG. UNIT: 5  MT STATE: WRIT'N.   130 PHYS REC WRITTEN IN   1 FILES
STREAM 1 RUN STARTED AT  2: 0:26.        3914 WORDS IN LAST READOUT CYCLE
TESTING APPLIES TO NEUTR. BEAM.
WEST CLOCK ON      PICTURE #  ON      BC MASTER  ON      FLASH VETO ON
D.P. STAT. OFF     MONITORING SCAN    DEV. MODE  OFF     HADR. WRIT.OFF
STROBE SRC OFF     A1,A2 COIN ON      BEAM SYNC  ON      PRIORITY   HIGH
CHAMBERS UNMASKED:
 1,  2,  3,  4,  5,  6,  7,  8,  9, 10, 11, 12, 13, 14, 15, 16, 17, 18,
19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36,
37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54,
55, 56, 57,   ,   ,   ,
CHECK LEVL  0      TEST FUNCN  0 WITH SCAN MODE OFF      SEQ. STATE:REPEAT
CYCLE DUMP OFF     CYCLE PRNT OFF     ERROR STOP OFF     RETRG MODE OFF
HIST. OFF
STREAM 2 PASSIVE      472 WORDS IN LAST READOUT CYCLE
STROBE SRC OFF     A1,A2 COIN ON      BEAM SYNC  OFF     PRIORITY   TSHARD
CHAMBERS UNMASKED:
   ,   ,   ,   ,   ,   ,   ,  8,   ,   ,   ,   ,   ,   ,   ,   ,   ,   ,
   ,   ,   ,   ,   ,   ,   ,   ,   ,   ,   ,   ,   ,   ,   ,   ,   ,   ,
   ,   ,   ,   ,   ,   ,   ,   ,   ,   ,   ,   ,   ,   ,   ,   ,   ,   ,
   ,   ,   ,   ,   ,   ,
CHECK LEVL  0      TEST FUNCN  1 WITH SCAN MODE ON       SEQ. STATE:REPEAT
SET OF CHAMBERS BEING SCANNED:
 1,  2,  3,  4,  5,  6,  7,  8,  9, 10  11, 12  13, 14, 15, 16, 17, 18,
19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36,
37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54,
55, 56, 57,   ,   ,   ,
CYCLE DUMP OFF     CYCLE PRNT OFF     ERROR STOP OFF     RETRG MODE OFF
```

Figure 14. EMI status summary on Tx 4010 screen.



```
B-EMI  WIRE MAP. CHAMBER #38   2/ 8/77.     2:59:49.     NEU =  5028
     *ALL CHAMBERS UP*
```

```
EFFIC.  A1  62.852  A2  62.396  C  62.951
M/CLW   A1   1.496  A2   1.488  C   2.593
        RATE =    1177.08 EVS/SEC
        UNDERFLOW =      0 OVERFLOW =      0
```

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Figure 15. Wire map of EMI chamber No. 38 exposed to cosmic rays.

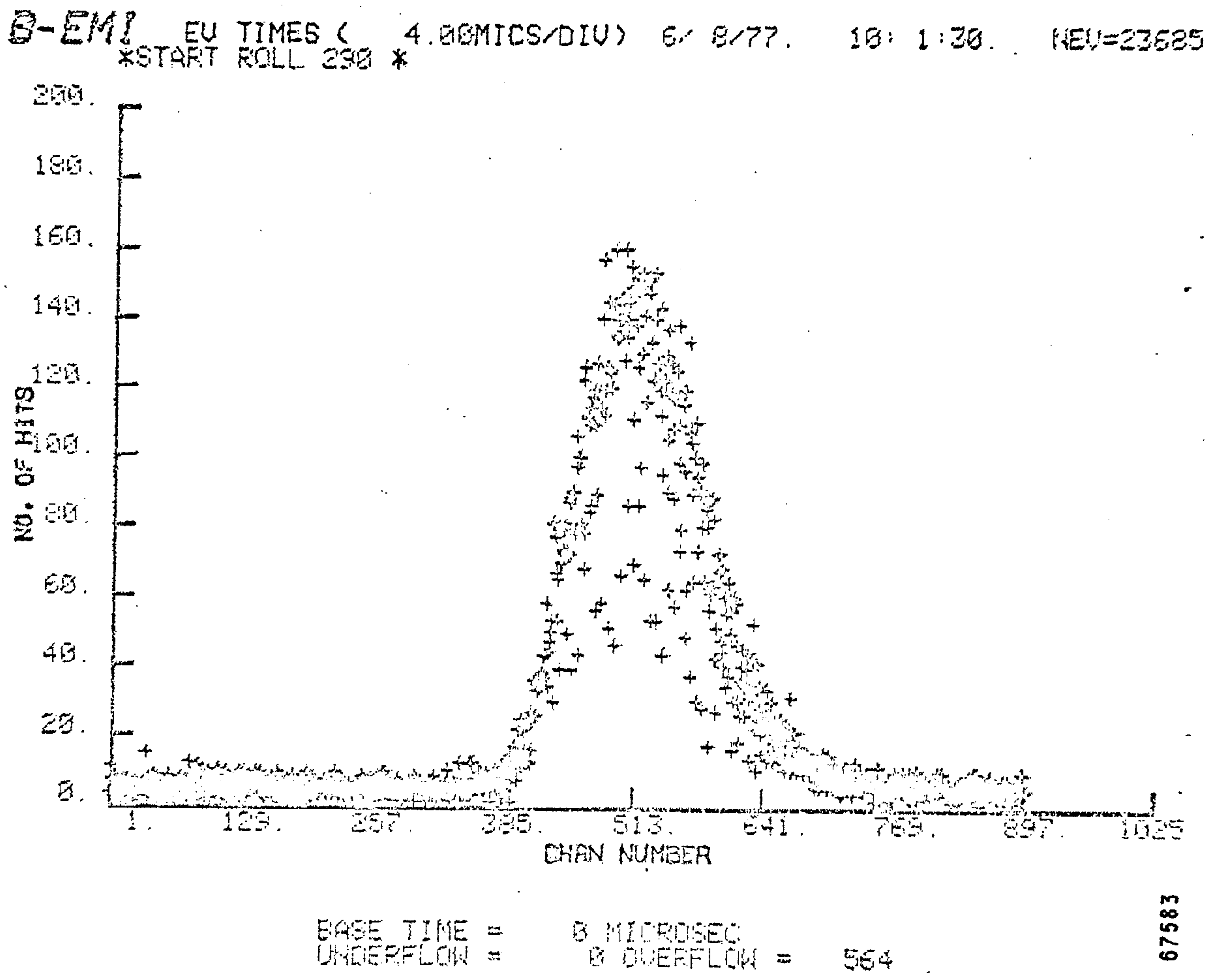

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Figure 16. Intensity/time distribution of Wide Band neutrino beam as measured by event times in the BEBC EMI.

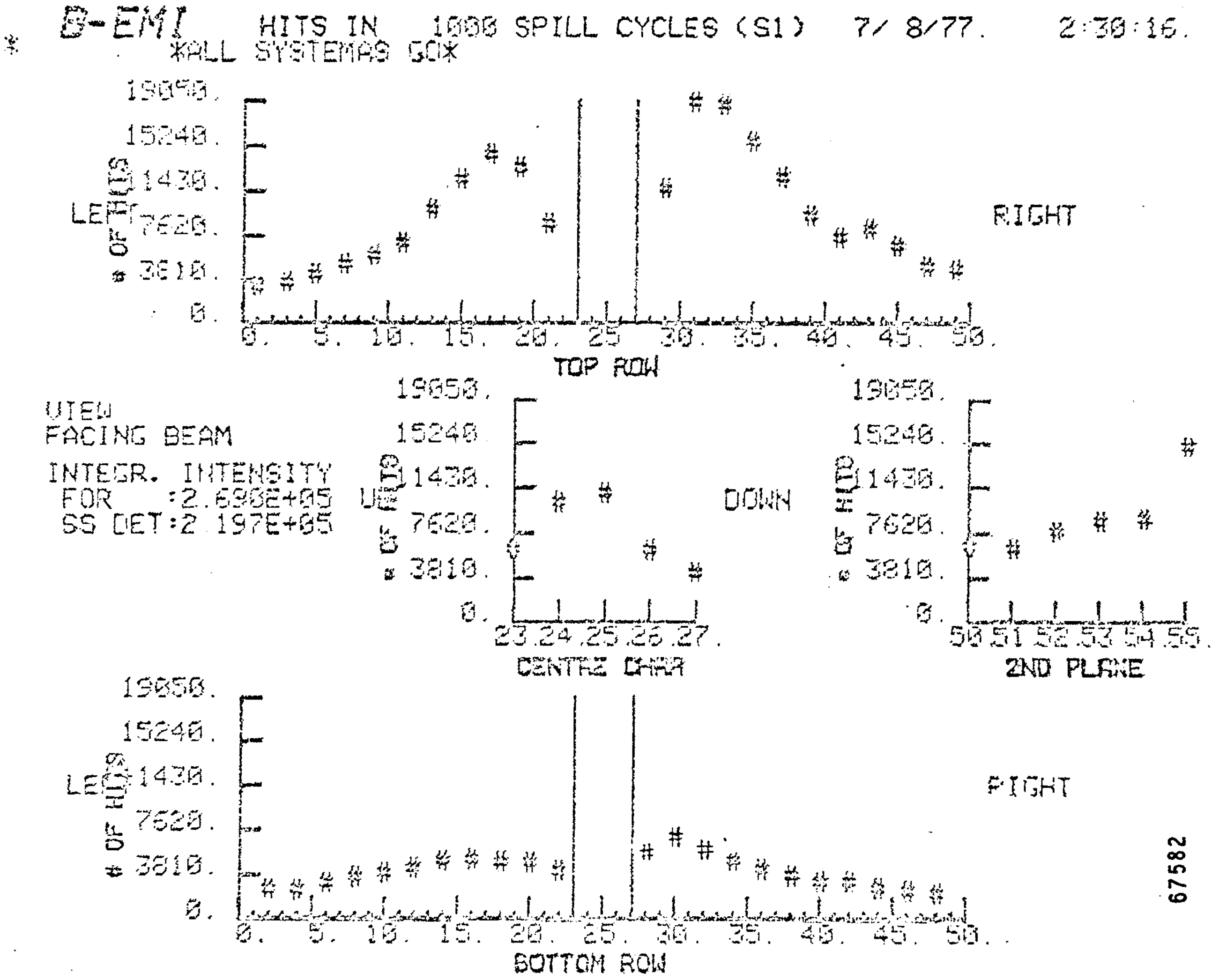

Figure 17. Intensity/space distribution of the Wide Band neutrino beam as measured by the hit rates on BEBC EMI chambers.