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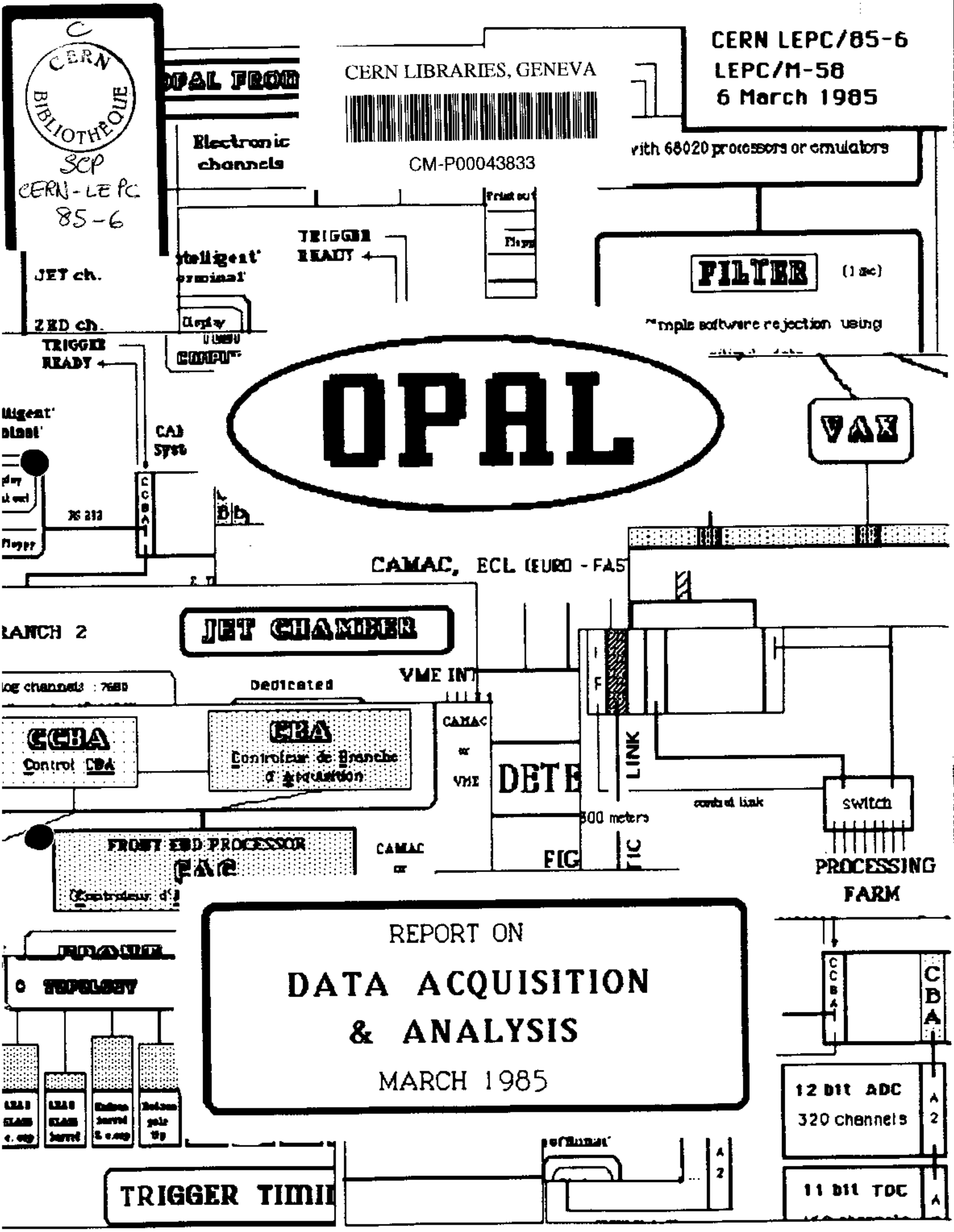


REPORT ON
DATA ACQUISITION & ANALYSIS
MARCH 1985

CONTENTS

1. INTRODUCTION

In January 1984 the OPAL collaboration produced a report to the LEPC on Data Acquisition and Analysis (CERN/LEPC 84-2). Work done since that time has allowed clarification of many of the details of the data collection process, and has also identified those areas which require further study. This document describes the present design of the data collection system and the current status of offline computing.

The following chapters of this document contain of an overview of the data collection process, followed by details of the hardware readout system. Chapter 4 covers online software aspects. Online hardware and software development timescales are covered in chapter 5, followed in chapter 6 by the status of offline computing. Finally, we list the requests made by the collaboration for support from CERN.

2. DATA ACQUISITION OVERVIEW

The OPAL data acquisition system collects information from twelve detector branches and delivers the information through an hierarchical tree structure to a master interface built in VME where individual events are assembled, ready for delivery to mass storage. At various places in the tree, connections are provided to local test computers, and there are facilities for controlling the data flow and arrangements for controlling the detector.

The OPAL detector, having signals from all its elements (including tracking detectors) ready within fifteen microseconds, is suited to provide high quality, low background hardware triggers within the bunch-crossing interval. A software filter and a third level selection process supplement the trigger and ensure that interesting events are efficiently isolated for special study. Figure 1 shows the flow of the event selection process.

The technology employed for data collection follows the OPAL philosophy of using tried and tested techniques to minimize the risks of failure or delay. Crate and bus norms are of at most three kinds, and, higher up the tree, the VME norm is used exclusively. All microprocessors in the system are of the same family, which is the MC68000-series recommended and supported by CERN.

A local area network (LAN) will provide a route for information transfer independent of that used for data acquisition. The network will be used to pass messages like bootstrap instructions, diagnostics and control commands, and will allow most terminals in the system to be connected at will for purposes of computer dialogue, monitoring and control. It is intended to provide a protection scheme to prevent this extreme flexibility from being misused. For the implementation of the LAN, Ethernet is favoured at present, but the choice will be delayed for at least a year, in the hope that a cheaper solution having the required characteristics of throughput, standardisation, and ease of use will become available.

Messages can also be passed inside the data collection tree, and in some cases beyond it, by the use of our PALABRE message protocol, which will be available throughout the higher levels of the tree.

The human interface of the on-line system will include intelligent terminals, probably using the PILS language for control. The Macintosh computer is being used for tests by at least two teams, but care is being taken to avoid computer dependence at this point, so that we may standardise on whatever seems best when the bulk of our terminals are purchased.

Our preferred mechanism for data storage is a link to the CERN computer centre and a comprehensive management service there. Some data will, nevertheless, be recorded on local 6250bpi tapes for special offline processing.

Various additional facilities will obviously be required before the detector comes on line. Methods of archiving and retrieving geometrical and calibration data, arrangements for providing additional high-level filtering capacity, and format conversion between VAX acquisition and IBM-style processing are all being studied actively, so that a fully operational on-line chain is assured well ahead of the LEP machine start-up date.

3. DATA ACQUISITION HARDWARE

3.1 Hardware Trigger (level 1)

Bunch crossings in the LEP machine will occur with a frequency of about 45kHz, while interesting events are expected at a rate of about 1Hz in LEP phase 1. Most of the required reduction will be achieved by the first level trigger, although more complex decisions will be left for software filtering higher up the data acquisition tree.

Typical interactions which should be rejected by the trigger are those due to beam-gas, beam-wall (off-momentum particles), synchrotron radiation, cosmic rays, and electronic noise.

Criteria available for use in the trigger include event topology, multiplicity, total energy, vertex position, and various conditions arising in the muon and forward detectors.

The slowest of these decisions is complete 15 microseconds after the bunch crossing. A further period of 3 microseconds is then available to combine these individual criteria prior to issuing a reset signal, if necessary, in time for the next bunch crossing. The decision process uses a RAM table lookup followed by comparison. Figure 2 shows the flow of these decisions and the time taken by each.

The table lookup mentioned above is in two stages: first the track elements are correlated with the theta-phi positions of individual detector elements in order to obtain information about collinear tracks, electron and muon candidates. Conditions in the individual detector components can then be combined in a trigger matrix, whose elements have been preset and can be changed during the run to adjust for background. Appendix I describes this matrix and its operation in more detail.

3.2 Front-end Data Collection

Front-end data collection is performed in a series of stages, described below.

Each detector group is supplying its own equipment at the lowest level, where complete standardisation has not been insisted upon: CAMAC is used when the number of analogue inputs is small; ECL-type arrangements in Fastbus crates or Eurocrates are employed to handle large volumes of data. Each such crate contains a scanner which assembles the information and performs various hardware-oriented data reduction tasks. Zero-supression, pedestal subtraction and the detection of clusters are all done by this scanner before the reduced data are passed on to the front-end processors.

Figure 3 shows the components of a typical detector branch, while Table 1 summarises the precise arrangement for each branch. Detailed diagrams describing each detector branch can be found in appendix II.

A suitable bus then conveys the data to a system crate for each detector, where the second level trigger is applied, and detector-specific spying may be done.

3.2.1 Front-end processors

The front-end processors are M68000/68020 running at 8-12 MHz, with 128kB of EPROM and 256kB of dual-port RAM. These units (CBA), housed in the detector system crates, drive the various chassis containing the digitisers. They acquire the data previously computed by the scanner, format it, prepare for the software trigger, and where possible parameterise the raw data in order to reduce the size of the event. Histograms for control and some statistics can in principle be done in these processors.

3.3 Detector System Crates

The detector system crate is the interface between the various norms used for data collection from the individual detectors, and the homogeneous, all-VME system used for assembling the event.

There is in general only one system crate for each of the twelve detector branches. The purpose of the system crate is to manage the trigger interrupt and to ensure synchronization between triggering and information gathering. It is at this point that events may be spied on for sample calculation, test or display on test computers which are the choice of each detector group. This is where control of detector parameters will be performed.

3.4 VME Master Interface

This is a matrix, having a M68000-series microcomputer for each detector branch and a number of parallel channels to give multiprocessing capability. It is housed in seven VME chassis, some detector types sharing a line of the matrix with others. The matrix will initially have eight parallel channels (columns), but up to 16 channels could be accommodated if necessary.

Each of the parallel channels contains in its seven computer memories the data for a complete event. These memories are addressable via a VMX highway by a MC68020 processor with floating point coprocessor (the event processor) which can therefore assemble the event and work on it.

Each of the memories is provided with two ports, to allow access both to the VME bus and to the VMX highway. Thus data from a particular event can flow in parallel streams from the detector branches to a single column of the matrix while a number of other events are being processed simultaneously in other columns.

This matrix scheme is illustrated in Figure 4.

3.5 Data Transmission to Ground Level.

All parts of the readout chain so far discussed will be situated underground at the intersection region. The final stages of data collection and recording will be performed in a surface building. A long-distance, high-speed link will therefore be required to bring data to the surface.

The exact specification of this link is still under discussion, but one promising solution has already been identified. This employs standard, commercially available plug-ins to implement a VME to VME link, and uses a fibre optic connection with a bandwidth of 20 Mbyte/sec, matching the VME bus speed. Such a link would terminate in a VME crate close to the OPAL main computer complex at ground level, providing a convenient point at which a farm of processors or emulators could be attached.

A possible structure for the link is shown in Figure 5.

3.6 Final Processing and Supervision

The final stages of data processing, and all supervisory activities, are accomplished in a complex of Vax computers configured as a cluster. This method of connection has been chosen in view of the considerable flexibility which it gives in the allocation of jobs to particular processors. Furthermore, the pooling effect of the cluster allows graceful degradation in the event of a hardware failure.

It is at present planned to interface the VME system to the Vax Unibus. Studies indicate that this will handle the anticipated data rate with some reserve capacity. At least two Vax systems would be interfaced in this way. An attractive alternative would be to connect the surface VME system directly to the cluster CI bus or to the star coupler, but it is unclear whether such an option will become available early enough to be of use.

The cluster itself will consist of a Vax 11/750, two 11/780, and an 8600, with an aggregate of 1.3 Gbytes of disk storage and 24 Mbytes of main memory, and with a range of smaller peripherals connected to specific processors having support for shared access through cluster software.

3.7 Data Recording

In previous reports, the OPAL collaboration indicated a preference for data recording at the CERN computer centre via an appropriate fast link. We wish to repeat our request that this be supported by DD division.

The present fallback recording medium (6250 bpi magnetic tapes) is the only medium currently supported at CERN, and has major drawbacks. The anticipated recording rate of 50 tapes/day represents a significant operational and administrative load on the collaboration. Tape recording hardware represents a serious budgetary committment by OPAL, and a large investment in it would create a situation which would have to be endured for the first few years of LEP. In addition, the production by the collaborations of enormous quantities of tapes would constrain CERN and the Member State Laboratories to provide tape support services for a prolonged period.

The collaboration therefore very strongly believes that alternative transportable bulk recording media must be sought soon. It seems unlikely that such media will be usable in time unless work is started immediately at CERN to achieve this. We further believe that only a central recording facility will have the resources to adapt as new devices become available.

4. DATA ACQUISITION SOFTWARE

4.1 Message Exchange System

The basic tool used for coordination of all software activities in the Data Acquisition System is the mechanism for exchange of information between programs. The OPAL message system is layered such that a standard information format may be used with a small number of different transport mechanisms. Gateways are provided between transport mechanisms where required. Figure 6 shows the routes available for message transmission.

All necessary dialogue between processors in the front-end microprocessor tree is carried out using the data collection path as transport medium. This is possible as the data bandwidth is high and the messages are in general short. Most messages are able to wait for a pause in data flow before being transmitted. The microprocessor tree structure enables routing tables to be fixed, while the master slave relationship between communicating processors facilitates simple and efficient message dispatching. With the exception of the main data flow, the messages most commonly carried in this part of the system are for program code loading and checking, task synchronisation, table loading, histogram and statistics collection, and error reporting. A pilot version of this system is already operating at Saclay.

Within a Vax computer, messages are passed using tools provided by VAX/VMS. The LAN is used for messages between Vax machines and to give access to other equipment at ground level. We are greatly concerned by the lack of standard high-level protocols for equipment connection on Ethernet, and request that efforts by CERN to develop appropriate standards be intensified. Much of the required message functionality is already present in current Vax acquisition systems, and a study is underway to provide a complete specification of required message functions.

A gateway will be provided between the Vax and microprocessor message systems, and this is expected to reside in a Vax computer. This should allow Vax programs to address microprocessor tasks by function, and will enable the fixed front-end addressing scheme to access transient software in a Vax. Message fields for use by gateway software are reserved in the front-end message format, but the contents are ignored.

A pilot project is underway to determine whether the facilities of the message system can be employed to present a uniform operator interface to all online software. In its early stages, this project will use a personal computer to access histogram information held in the Vax acquisition system. It is hoped to extend use of PCs in this way to include the slow control system and acquisition suite as well as user-written monitoring and filtering programs.

4.2 Data compression

Data compression is carried out as early as possible in the readout chain, since this maximises the number of good events which can be transferred to higher levels, and simplifies all subsequent processing. The removal of baseline values and the parameterisation of data is done where possible for each detector. The jet chamber accounts for a large majority of the data compressed in this way, and for this reason it is described as an example below:

The jet-chamber of the OPAL central detector comprises 7680 electronic channels. The amplitudes of the channels are digitised every 10nsec by flash ADCs, resulting in 3.8Mbyte of data for a raw event. As most of these data correspond to baseline, a first reduction can be made by selecting only the non-trivial data, which correspond to a particle track. This amounts to approximately 200 kbyte of data for a Z0 event with a particle multiplicity of 20. For track elements which are not too close to each other, a further data compaction process is possible. This involves comparing the digitised chamber pulse with a reference pulse. Approximately 60 bytes of data from a raw pulse can be reduced to 12 bytes representing the 3 space coordinates, the charge and the pulse shape. Assuming that this reduction is possible for 2/3 of the data, less than 100 kbyte of jet chamber data need be recorded for a typical Z0 event. Performing several such compaction operations in parallel at the detector system crate level allows the dead time to be kept to a minimum.

4.3 Event Filter (2nd level)

This is purely a software process, and is performed in the filter interface (FIF) which is the 68020 processor where the event is available in its entirety for the first time.

The process is in two stages: initially, the first level trigger process is repeated with finer granularity and greater precision. This allows the rejection of events which should never have been read out; next, some (fairly elementary) analysis is done on the event to assess whether it is a simple one, (Bhabha, muonic, two or three prong) or whether it is an event which merits elaborate analysis. Simple events are analysed on the spot, while more complex events are flagged for later processing.

4.4 On-line processing (3rd level)

The events which are retained by the FIF are written to mass storage. Selected events are further processed either in the VAX or in a processing "farm".These processing facilities will also write their results to mass storage, probably on separate streams.

The farm will be used for the routine processing of events which need detailed on-line analysis. The VAX will analyse those events which merit interactive investigations and detailed on-line surveillance. The fact that these interactive investigations are both elaborate and multi-access means that we need as much VAX power as possible, and it is intended to use the capacity of the 8600 configuration at this point.

4.5 Monitoring

The purpose of monitoring is to identify faults and unexpected conditions which jeopardise the quality of recorded physics data, and to provide on-line first-level physics analysis of the data.

Because of the size and complexity of the OPAL detector, the monitoring system has to check not only the status of the Detector and the LEP Machine, but also the hardware and software integrity in the several levels of the trigger and data collection systems.

4.5.1 Detector Checking Procedures

The most powerful tools available for monitoring are histograms and statistical information created by analysis of data samples. Some of the outer detectors in OPAL are, however, illuminated by particle tracks only infrequently. For these detectors, the time to accumulate histograms may be very long, even if every event is processed. To overcome this, it is intended to use detector calibration systems to produce pseudo-events at regular intervals.

4.5.2 Computer resources for Monitoring

It is intended to carry out monitoring work to some extent in all parts of the data collection chain. However, the CPU and memory resources required are such that extra, dedicated monitoring processors may be required to supplement Vax and Front-end capacity. OPAL has recently reviewed planning in this area, and it is now proposed to consider use of a further farm for this purpose. For this purpose, 68000-family processors are probably the best choice. The farm would be connected between Front-end and Vax, so that data could be obtained on the fly rather than by retransmission from the Vax.

4.5.3 Histogram Rotation

The number of histograms and statistical tables required is expected to be very large, and some overall control of monitoring will be required to ensure fair distribution of resources. In this case, histograms would be filled in rotation from a disk based store.

4.5.4 Operator Interface

A uniform user interface to monitoring software will be required to shield users from the details of accessing and using specific processors. Such an interface is partially implemented in current Cern Vax packages, but will need extension to handle the multiprocessor environment in OPAL.

Histogram information will be transferred from source to display device in a standard format, independent of the place where the histogram was filled. A Personal Computer is currently under evaluation as a histogram display device, and it is hoped to make a pilot version of display software on a PC available for evaluation by the detector groups in mid-1985.

4.5.5 Automatic Checking Procedures

As the amount of histogram information is expected to be large, an automatic histogram checking program will be used to complement operator checking procedures. This program will have to cope with many user-written monitor programs which change with time, and to understand different possible trigger and beam conditions. Although some good guesses may already be possible, it will be difficult to predict exactly which checks will be most useful until the detector is running with beam.

4.6 Data acquisition in the VAX Cluster

The final stage of data collection and organisation prior to recording will be carried out in the Vax complex, which is also responsible for overall control and administration of the experiment.

Data entering the Vax cluster will be placed in one of several recording streams, using event classification obtained from previous analysis. Samples of data will be made available for monitoring software which requires resources available only on a Vax.

A significant part of the workload of the Vax cluster consists of activities which are external to the main data flow but which are crucial for smooth running of the experiment. Work in this category includes data base management, network operation, equipment and run control, support of microprocessors, provision of interactive program development facilities for the collaboration, and other activities mentioned elsewhere in this report.

OPAL has for the last year been using the CERN Vax Data Acquisition package in support of test beam work, and has therefore been able to carry out an evaluation of the suite under running conditions.

As a result of this work, it has become clear that there are areas where major modifications will be required for the package to be used efficiently by OPAL in the final experimental setup. Discussions on how this might be done are underway. Continued support for the current package will nevertheless be required in the short term.

4.7 Calibration System

Some details of the detector calibration equipment to be used have been presented in previous reports. This section is concerned with the integration and implementation of calibration in the online system.

The OPAL calibration system is particularly simple to implement since it is able to benefit from the facilities provided in the data collection chain. This is also the case for many other OPAL subsystems.

Calibration interfaces for each detector will be located in the crates also used for control interfaces. Injection of signals into the detector will therefore be started by programs running in the slow control microprocessors. Signals will also be sent to the trigger system, to initiate readout of the data. The wide variety of calibration procedures expected will be accommodated by implementing the details of work for each detector in an interactive language, probably PILS, with an interface to the message system.

As far as possible, software for analysis of calibration data will be permanently loaded in all processors. This will allow rapid evaluation of constants with minimal quantities of data to be sent to higher parts of the readout system. Parameters so computed will be stored in the online database, from which copies of required information can be retrieved by other software as required.

4.8 Data Bases

The collaboration is just beginning to work in this area. We are currently building up a catalogue of the different kinds of data that OPAL will have to handle. At the same time we intend to acquire hands on experience of the SQL relational data base system now available at RAL, and possibly ORACLE at

CERN. We hope to combine these two activities by trying to construct a simple Data dictionary for the OPAL data. For evaluation purposes, we request CERN assistance both in making available a small number of commercial database systems for trial, and also in supplying advice and expertise in their use.

4.9 Slow Controls

Controls are interfaced through hardware supplied by individual detector groups. This hardware will probably be CAMAC-based, but could use any of the bus standards supported by OPAL. The hardware which is so interfaced will be accessible either locally, from a terminal attached at crate controller level, or from other locations through the OPAL message system.

Control programs can be constructed in the terminals, which will be microcomputer based and will have the capability of interpreting a control language and showing a user-friendly interface. Current thinking on these terminals is to use the Macintosh personal computer, for which the PILS interactive control language will be supported by CERN/DD.

The message system, which gives access to all VME crate controllers as well as all VAX computers in the system, can provide control facilities at all desired locations in the pit and the surface building. This also implies that control algorithms can obtain their data not only from control crates, but also from any source needed. It is envisaged that access protection will be needed to prevent accidental changes to vital detector parameters during the running of the experiment.

5. DATA ACQUISITION TIMESCALE

	85 86 87 88 89
Prototype VME Hardware	-------|
Prototype System at CERN	|---------------
LAN choice	|--|
Integration with individual Detectors	|------------
Prototype LAN Hardware	|--|
Prototype Fibre-optic Link	|--|
Installation in I6	|-|

	85 86 87 88 89
Microprocessor Systems Software	---------------- - - - -
VAX Message Software for OPAL	---------------- - - - -
VAX-based Acquisition Software	|--------------- - -
Control Software	|----------- - -
Data Base	|----------- - -
Cluster Systems Integration	|---|

6. OFFLINE COMPUTING

6.1 Offline Computing Capacity

The OPAL collaboration has estimated that it will require 10-12 units of IBM 168 computing power to process and analyse data from the OPAL detector at LEP 1 (CERN/LEPC 84-02).

6.1.1 Central computing power at CERN

We understand that CERN will provide only three units of 168 power on the Central main-frame computers and is itself considering emulators and microprocessors as a source of further computing power. OPAL supports the study of emulator and microprocessor farms by CERN groups. We have already benefitted from the assistance of the Schmid group in attaching a 370/E to our Vax 11/780 system on the CERN site. We encourage CERN to support this and other similar groups to go on to develop a **central facility** with a capacity for a high data transfer rate between the emulator and the data storage media. Emulator and microprocessor facilities could make a significant contribution in reducing the shortfall in computing capacity in the CERN planning for the LEP era. In the OPAL institutes we have found a number of advantages in having a host which is compatible with the attached processors. CERN should consider providing IBM emulators attached to an IBM 43xx series computer in the CERN computer centre.

6.1.2 OPAL computing power at CERN

There is some uncertainty as to what the OPAL computing power at CERN will be at the time of LEP start up. A large IBM compatible mainframe may be brought to the CERN site but as the funding for this is not yet guaranteed we do not wish to take this into account at this time. The provision of 4 370/E emulators to be used for offline analysis and hosted by an OPAL Vax is currently recommended for funding by the OPAL collaboration. This corresponds to approximately 2.3 168 units of processing power. The host and peripherals for such a system is still under discussion and we hope to learn from the efforts of the Schmid group.

The Vax family of computers in the OPAL computing system is likely to comprise one 8600, two 11/780 and one 11/750. There will be considerable processing power available for online monitoring and filtering of raw event data and there is some **speculation** that the processing power of the data acquisition system may also be available for offline data reduction in the style of the Nash FNAL ACP. (This may give 2000 hours per year of the power of 3 168 units.)

6.1.3 OPAL computing power off the CERN site.

There is considerable processing power in the home institutes of the members of the OPAL collaboration. This enables these institutes to make contributions to the development of software and eventually to final analysis. We estimate that 4-5 units of processing power are available in sites which could handle a bulk processing task with a stable production program. Nevertheless it is clearly desirable to perform all data reduction and processing at a central CERN site, particularly at the early stages of an experiment. We would not willingly distribute large volumes of data for processing at home institutes but would prefer to use this capacity for individual analysis topics.

6.2 CERN Computing Systems.

6.2.1 OPAL computer systems

The major OPAL software work at CERN in 1984 has been the analysis of data from the prototype section of the Central Detector and the representation of the OPAL detector in the framework of the developing Geant3 simulation program. The interactive debugging and graphics facilities on the VAX 11/780 machine maintained at CERN by OPAL have been essential to this work. F.Chevrier, J-P Droulez and M.Znoy have given valuable technical and managerial support for the OPAL Vax machines and we ask that this support should be maintained. The VAX 11/780 machine may be accessed by many OPAL institutes via the international X25 network.

The OPAL 370/E emulator was brought into production use at CERN in 1984 and has proved its value in cpu intensive tasks in the study of hadronic and electromagnetic shower codes. Since January 1985 the host has been the OPAL Vax 11/780.

6.2.2 CERN central computer systems

OPAL made little use of the CERN IBM system for software development in 1984. Apart from the restrictions of the Wylbur editor, we found the busy MVS system inadequate to debug a program occupying 2Mb memory size and taking a processing time of the order of a minute to reach the point of interest within the program.
In 1985 we have made use of the abundant cpu power available at CERN following the upgrade of the IBM systems. This has provided a valuable contribution to the final stages of the simulation of the OPAL hadron calorimeter.

We are disappointed at the slow response to our request to register users on the VM/CMS service, all the more so as we have started to build up our software group at CERN and would like to avoid the overhead of teaching users the MVS/Wylbur system. We urge CERN to proceed with the introduction of a interactive VM/CMS service on the central computer system. We request that the production service will provide graphics and full screen terminal facilities on "CERN standard" devices such as the Pericom 7800 series, with a high data transmission rate.

We are pleased to note the arrival of a VAX 8600 (Venus) computer which is primarily for use by the LEP groups. We request that there should be no delay in providing terminal access to this machine via the Index system.

OPAL has made little use of the CERN CDC machines running under NOS/BE and currently has no plans to make significant use of this system.

6.3 Networks

OPAL has already found that having some means of gaining access to computers on the CERN site is essential to the effective involvement of home based physicists and programmers in the rapid development and testing of software packages. The OPAL Vax 780 has recently been connected to the CERN multigate system to provide X25 access to public networks and the UK (JANET) network. OPAL Italian and French groups have access via INFNET and DECNET. The EARN/Bitnet experimental VM network has proved valuable to OPAL, giving mail and some job submission facilities to groups in Germany, Israel and North Amer-

ica. OPAL has provided ad hoc software to distribute message files between JANET community and the CERN Wylbur/MVS and VM network.
These diverse facilities go some way towards a short term solution to the immediate problems of physicists in home institutes.
There is an urgent need for internationally accepted network protocols which support terminal, job manipulation, mail and file transmission and inter-program traffic between computers from different manufacturers and in different countries. We urge CERN to maintain their efforts to improve products in this area.
We request that our office management and word processing facilities should be fully integrated into future electronic mail system. In the short term we wish to connect our Wang system to the IBM service to make use of the currently available facilities for the distribution and collection of information.

6.4 Graphics workstations

The development of a high-quality 3D event scanning system is considered to be essential for the verification of the reconstruction and interpretation of complicated and rare events. CERN/DD work in this area appears to be concentrated on the PIONS package which currently drives the Megatek calligraphic display and other devices. Some OPAL institutes have groups which have Megatek devices to scan events from experiments such as UA1 and UA5. None of them have an implementation of PIONS. The proprietry software for these devices has now been upgraded in the form of the Wand package and this seems to give an adequate return for the investment required to interface to the users software packages.
We are confident that new graphics engines able to perform real time dynamic graphics with a large volume of information in their own databases will be available commercially in 1985. However, given the current lack of a GKS implementation on the CERN central computer system and the time scale envisaged for the emergence of future standards such as PHIGS, we are not confident that there will be standard interface to these systems on a time scale appropriate for LEP event viewing.
OPAL already has excellent 2D graphics software packages in use in its simulation program in several institutes which have already been used as an aid to detector design and simulation and to the development of pattern recognition algorithms.

The OPAL graphics data structures preserve 3D co-ordinates and attributes to the lowest level of the program. Convertion to a 3D system at this low level is forseen to be a relatively routine task. One major problem is the need for multiple mappings of the extensive OPAL/Geant3 data structures, not only via the PIONS user routines into an enormous PIONS data structure but also into the display memories of current and future display systems.
We are currently reviewing our software and hardware resources throughout the collaboration and will then proceed to determine the most efficient way to proceed in collaboration with the PIONS group.

6.5 Software tools

6.5.1 Code management

OPAL currently uses Patchy for most code maintenance and distribution. We have initiated discussions with Opcode Inc in North America for a Historian license for our "non-European" groups. We have no plans for conversion to Historian in the short term but we may consider using Historian for source code maintenance at CERN and find a transport mechanism for "non-Historian" institutes.

6.5.2 Documentation

The documentation for major packages such as GEANT3, GOPAL (the Geant3 user routines specific to OPAL) and OPUTIL (a program library) are currently produced and maintained using the Script facilities at CERN. There are tools to manipulate these files to produce (Fortran) comments to be added to program source code. This information is also available interactively via a help system.
We intend to provide tools to extract comments from source code to produce documentation of programs and their data structures.

6.5.3 Coding conventions

An OPAL paper, Coding and Program Design Conventions, has been circulated to provide guide lines for OPAL offline software. Many of the ideas have been adopted from the Metcalf paper FORTRAN 77 Coding Conventions (DD/US/3). We intend to provide tools to verify adherence to coding conventions, these will probably be based on the FLOP program. We are pleased to note that the CERN program library has accepted our request to introduce character variables in place of, or in parallel with, hollerith variables where one would naturally expect to use them. We have not yet made a formal decision on the representation of bits within its online and offline environments.

6.5.4 High level languages

OPAL policy is to write software in Fortran 77 avoiding language extensions when ever possible, and to provide selection mechanisms whenever machine or compiler dependent code is essential.
We support the efforts of M.Metcalf to influence future Fortran standards to maintain a language which is compatible with the requirements of H.E.P. software.

6.5.5 Memory management

The Zbook system is currently employed in major OPAL software packages. We hope to be able to upgrade to the Zebra system in the near future.

6.6 Detector Simulation

The GEANT simulation system has been continuously developed over the past ten years. In 1983 work began on the new system, GEANT3, which puts more emphasis on the 3D representation of complicated geometrical set-ups. The OPAL collaboration has provided the major contribution to the GEANT3 program and the OPAL detector has been the major test-bed for the development of the GEANT3 code. The GEANT3 system allows one to:

1) describe a complex experimental set-up in a simple and efficient way,

2) generate simulated events from standard physics event generators.

3) control the transport of particles through the various devices of the set-up taking into account the geometrical volume boundaries, the magnetic field and physical mechanisms.

4) record the elements of the particle trajectories and the response from the sensitive detectors.

5) to visualize either interactively or or in batch mode, the detectors and the particle trajectories and the hits.

6) to save the result of each event on mass storage in a machine independent form.

OPAL has already developed a detailed representation of the detector. The code has been written for all of the elements of the detector to describe the material properties and layout in the GEANT3 framework. The response of sensitive detector elements to the passage of particles is stored in the form of hits. After the tracking step, the hits are fetched for each detector and the combined response is calculated and stored in the form of digitisations. The code for this calculation has been written for the Central Detector, the electromagnetic and hadronic calorimeter elements, the muon system and the calorimetry within the forward detector system. Work is currently in progress to complete the specification and coding for the pre-sampler around the barrel and the tracking chambers for the luminosity measurement within the forward detector. The digitizations will ultimately be stored in the same format as the data stored by the online data acquisition system.
The detailed tracking of all particles produced in a shower together with the detector response requires large amounts of computer processing time. We intend to develop techniques to parameterise the response of parts of OPAL using the results of the detailed monte carlo. Already, the mean number of photo-electrons produced by a track segment in a lead glass block is given by a parametrization of the results of an independent program to track Cerenkov light and model the photo-cathode response.

6.7 Event reconstruction

It is planned that the OPAL event reconstruction program will be designed and coded with an interactive graphics interface. It will have access to a data-base of calibration and survey information and the magnetic field mapping. Although we may draw a diagram of the flow of information from digitisation to physics analysis thus:

1) apply threshold and calibration information

2) track finding and pattern recognition in the central detector

3) track fitting

4) vertex fitting

5) kinematic fitting of decays

6) track extrapolation

7) time of flight information

8) calorimetry

9) particle identification

we expect there will be a complex interdependence of the information present in each of the detectors which will require a flexible and well designed analysis strategy to fully exploit the OPAL detector.

Many of our detector groups are writing reconstruction and analysis software in the home institutes in parallel with the development of the detector modules. An outline definition of the entire OPAL data structure has been compiled from the information submitted by the detector subgroups. This is being used to prepare a data dictionary which will form the core of both the eventual offline event data structure and of the detector status and callibration databases.
The GEANT3 package could provide the basis for a reconstruction program and we are awaiting the circulation of a preliminary specification from the GEANT3 authors.

6.8 The full scale prototype of the OPAL central detector

The program FUSPA (FUll Scale Prototype Analysis) has been developed for the testing of the OPAL full scale prototype of the Jet- and Z-chamber components of the central detector The aims of this program are twofold:

a) To allow detector studies under rapidly changing test conditions

b) To provide a development tool for the final offline analysis

6.8.1 Program structure

The program consists of a few steering routines which communicate with a number of analysis modules. During event processing the steering routines loop over the analysis modules to solve the problems arising from the inter-dependence of the correction co-efficients determined by each module.
The following modules are available for the analysis:

a) event display (pulse shape and track picture display for raw data and processed information)

b) treatment of 'extra' data (trigger counters, cherenkovs e.t.c.)

c) Jet-chamber analysis (submodules for hit finding, hit reduction and tracking)

d) Z-chamber analysis (submodules for hit finding, hit reduction and tracking)

e) event tracking (combining the track segments from the Jet chamber, Z chamber and trigger counters)

6.8.2 Data structure

The event length ranges from 5 k to 50 k (16 bit) words depending on the baseline suppression of FADC data and the number of tracks in the detector. The event records have a ROMULUS structure and the raw data tape format obeys the EPIO standard.
The memory menager used by the program in its present version is ZBOOK, a transformation to ZEBRA is expected to follow.
The essential structures in the offline data structure are an FADC raw data bank and an event result bank. The FADC raw data bank gives direct access to the FADC information of individual hits in the Jet- and Z-chamber. These hits are determined by a threshold based scanner implemented in the readout

hardware or, optionally, by an offline hit finding processor. Various algorithms for hit finding have been investigated.
The branches of the event result bank reflect the modules of the detector.
The pattern recognition program sets up pointer banks giving direct access to the information of track segments. The matching of track segments amounts to a renumbering procedure which does not change the structure of the event result bank.

6.8.3 Calibration

Calibration data reside on a direct access file which is manipulated by the CERN program KAPACK. A preliminary calibration record format has been defined and software aids for the interrogation and manipulation of calibration data are provided.

6.8.4 Present activities

At present the program supports the following activities:

a) detector studies
- optimisation of the operating point
- comparison of electronics
- evaluation of corrections
- stability of calibration

b) test of algorithms for hit finding and reduction with respect to tracking accuracy, energy resolution and particle identification for single and multiple tracks

c) adaptation of the pattern recognition program to real data (the pattern recognition program has already been applied successfully to Monte Carlo data).

6.8.5 Future plans

The OPAL Central Detector software group plans to:

a) continue detector studies

b) select the algorithms for the final analysis

c) prepare part of the algorithms for fast real time applications

d) apply algorithms to Monte Carlo data

e) communicate the data handling experiences gained for the Central Detector to the overall offline program.

6.9 Pattern recognition in the OPAL jet chamber

6.9.1 Introduction

The Jet Chamber, consisting of 24 sectors each having 160 sense wires, represents the major part of the OPAL central detector and provides up to 160 independent measurements for each charged track detected. An efficient method of pattern recognition is required to convert these measurements into particle trajectories and calculate the physical characteristics of the particles. This is the first step towards the complete reconstruction of events. The overall functions of the event reconstruction may be sketched as follows:

a) track reconstruction in the Jet Chamber. The measurements provided by this detector allow a spatial determination of the trajectories of particles

b) the definition of these tracks is then completed by using the measurements given by the Vertex and Z chambers detectors, the other two components of the OPAL central detector

c) determination of main and secondary vertices and fit of the track parameters

d) physics analysis

In the following, we give an outline of the method developed for the track finding in the Jet Chamber.

6.9.2 Track finding in the Jet Chamber

The track finding in the Jet Chamber is split in 2 stages:

a) a search for track segments is performed independently for each of the 24 sectors

b) segments of adjacent sectors are combined into complete tracks if they are found to be pieces of the same trajectory

The search for track segments within one sector is performed in the r,phi view only, as measurements in this view are orders of magnitude better than those in the r,z view. As the magnetic field is constant over the central detector, the trajectories of particles are arcs of circles in the r,phi projection. This property has allowed us to develop and implement a method of Pattern Recognition based on a conformal mapping transformation, which has worked very successfully on simulated events,reconstructing even complicated jet-like topologies with a high efficiency. (100 per cent for a sample of events generated without delta ray production.)
The main advantage of this conformal mapping technique is that it transforms arcs of circles passing near the origin into straight lines. The problem of track finding is then reduced to finding straight track segments in the transformed space, thus considerably simplifying the pattern recognition task. As a by-product, this method also provides first estimates of the track parameters.

6.9.3 Application of the track finding method

Since the summer 1984 a full size prototype sector has been operated n the OPAL test beam and the track finding algorithm has been applied to the real data obtained from this prototype. As the test data have been taken without magnetic field, the only modification to the reconstruction program was to suppress the conformal mapping, leaving the subsequent stages (straight line finding and fitting) unchanged. The pattern recognition program has been working as expected from simulation studies and has been used successfully to refine various calibration constants previously obtained by other means.
In addition,work is going on in order to combine the analysis of data coming from the Z chambers with the results obtained in the Jet Chamber prototype sector.

7. SERVICES AND FACILITIES REQUESTED FROM CERN

The OPAL Online and Offline Groups request the following services and facilities from CERN. The services requested are in addition to those listed in CERN/LEPC 84-2 except where explicitly stated.

a) Facilities (Space,Power, cooling,etc) for interim assembly of the OPAL Vax Cluster in 1987.

b) Completion of the I6 surface building SXC, with services, as soon after the installation of the surface crane as is possible.

c) Continued access to the services of CERN-DD Online Computer group to assist in all areas of preparation for data collection. We request that travel funds be made available to them for attendance at meetings outside CERN. We request their continued participation in the specification and design stages of the OPAL acquisition system. We further request the continued support of the present or enhanced CERN Vax Data Acquisition suite for use in test beams prior to LEP turn-on.

d) It is essential that CERN accept and standardise on a transportable bulk data recording medium by 1.1.86 at the latest. This is crucial for the design and testing of Online Systems. We request a Central Data Recording and retrieval service, based on the above medium and employing a simple direct link from I6. CERN processing services supplied to the collaboration should conform with the above standards.

e) We request CERN support for Ethernet and a cheaper compatible network which is suitable for connection to many microprocessors. We request that CERN plans to support these networks be studied duing 1985 and fixed by 1.1.86.

f) We request that CERN install a small number of commercial database systems for evaluation by OPAL. Until such evaluation is completed, and unless commercial products are found to be unusable, we would strongly urge CERN not to initiate a project to write an in-house database management system.

g) We request that CERN continue and extend efforts to reach agreement in the near future on protocols for use over Ethernet and the cheaper, compatible network discussed above.

h) We request that the existing limited support of VME be brought up to the level currently available for CAMAC over the next few years.

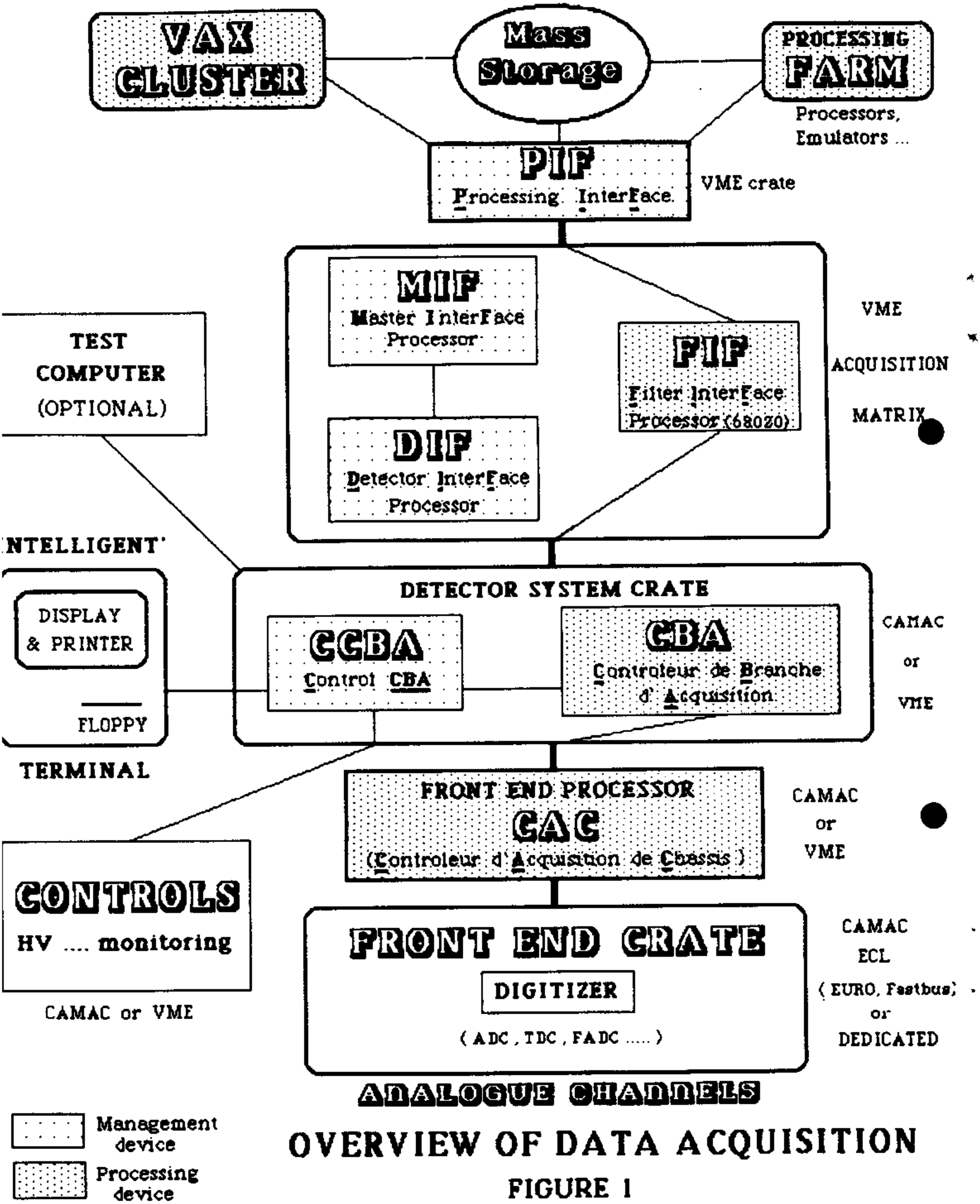
i) We request that the system and management support provided by CERN for the OPAL VAX computers should be maintained.

OPAL FRONT END ELECTRONICS

DETECTOR BRANCH	Electronic channels	TYPE	Reduced * Data Throughput (Kbytes)	Front end Data BUS	Front end processors CAC	CBA
VERTEX ch.	648	TDC	4,	ECL dedic. (13 crates)	---	8
JET ch.	7680	FADC	160,	ECL Euro : 80 cr or FB : 24 cr	80 (Euro) 24 (FB)	8 2
ZED ch.	2304	FADC	10 ,	ECL Euro : 24 cr or FB : 8 cr	24 (Euro) 8 (FB)	2 1
TOF	320	ADC. TDC	0,35	CAMAC (5 crates)	---	1
E.M. presampler	18432	ADC	1,5	ECL 10 FB crates	---	2
E.M. barrel	9440	ADC	0,55	ECL 6 FB crates	---	2
HADRON cal. (barrel & end cap)	56146	ADC Bit Pattern	1,	ECL (2FB) CAMAC (6)	2	2
MUON barrel	2240	ADC. TDC	0,05	Dedicated 20 Euro cr.	---	2
E.M. end cap	2300	ADC	0,5	not yet decided (2 to 4 cr.)	---	2
HADRON cal. (pole tip)	10576	ADC Bit Pattern	0,5	CAMAC (4 crates)	---	2
MUON end cap	38400	ADC or Bit Pattern	0,05	Not yet decided (2 crates)	---	2
FORWARD det.	2200	ADC FADC	2,	CAMAC (2 crates) ECL (4 cr)	4	2
TOTAL : 12 branches	150686	—	180,5	45 racks	6 Camac 105 or 32 VME	25 10 or 3

* For hadronic event (20 charged tracks).

TABLE 1
INTERFACE ARRANGEMENT FOR EACH BRANCH



OVERVIEW OF DATA ACQUISITION

FIGURE 1

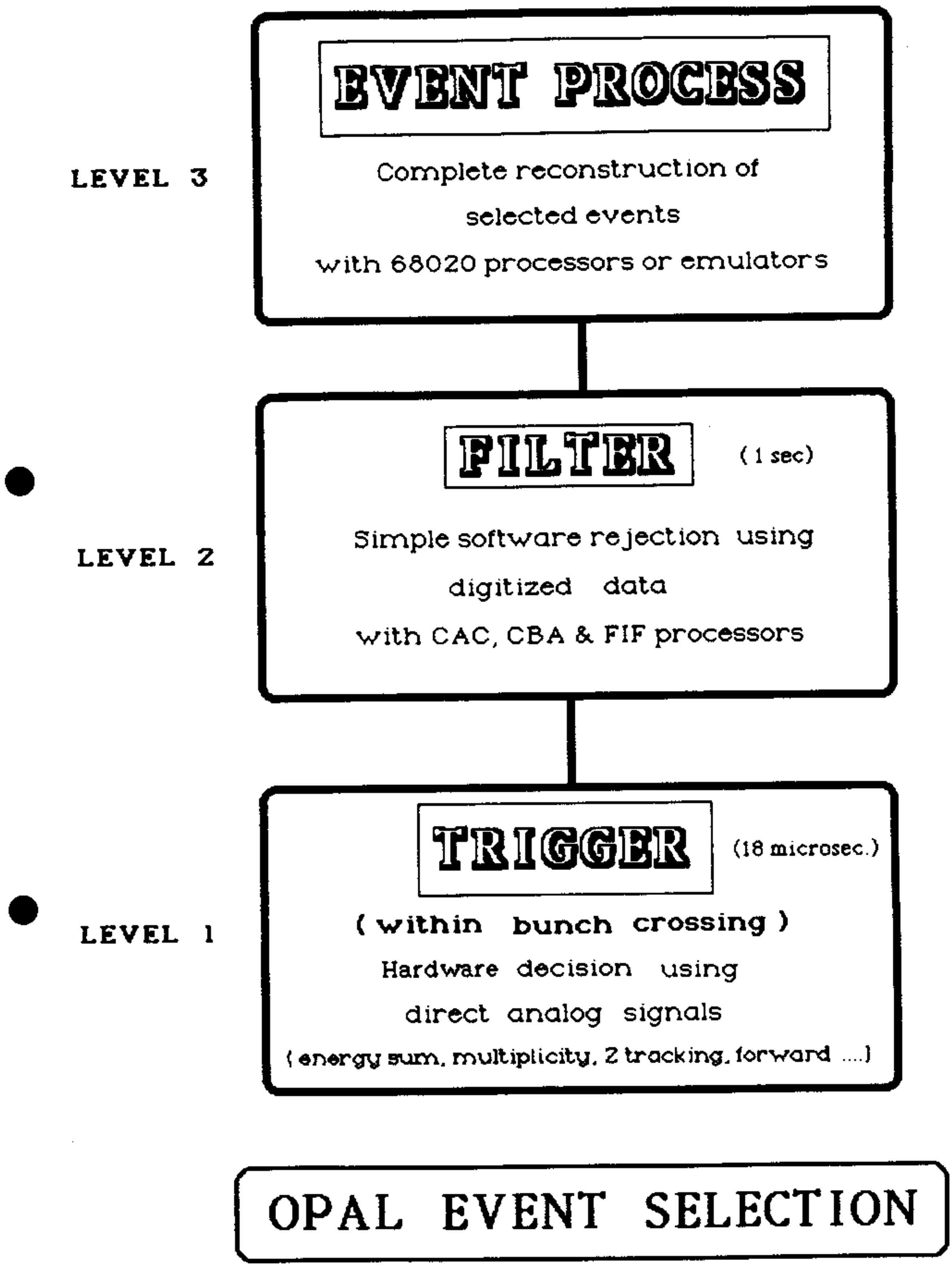
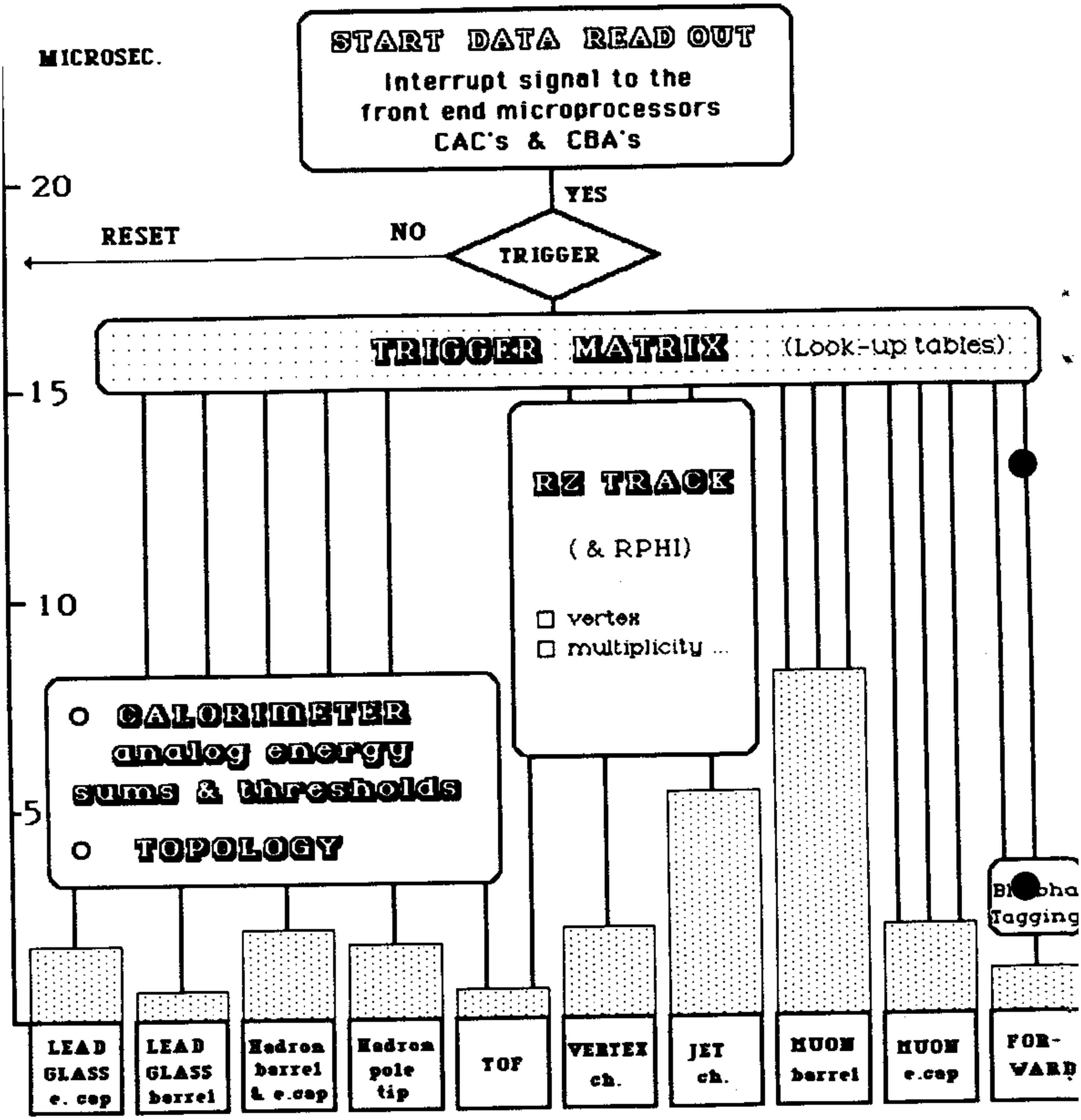
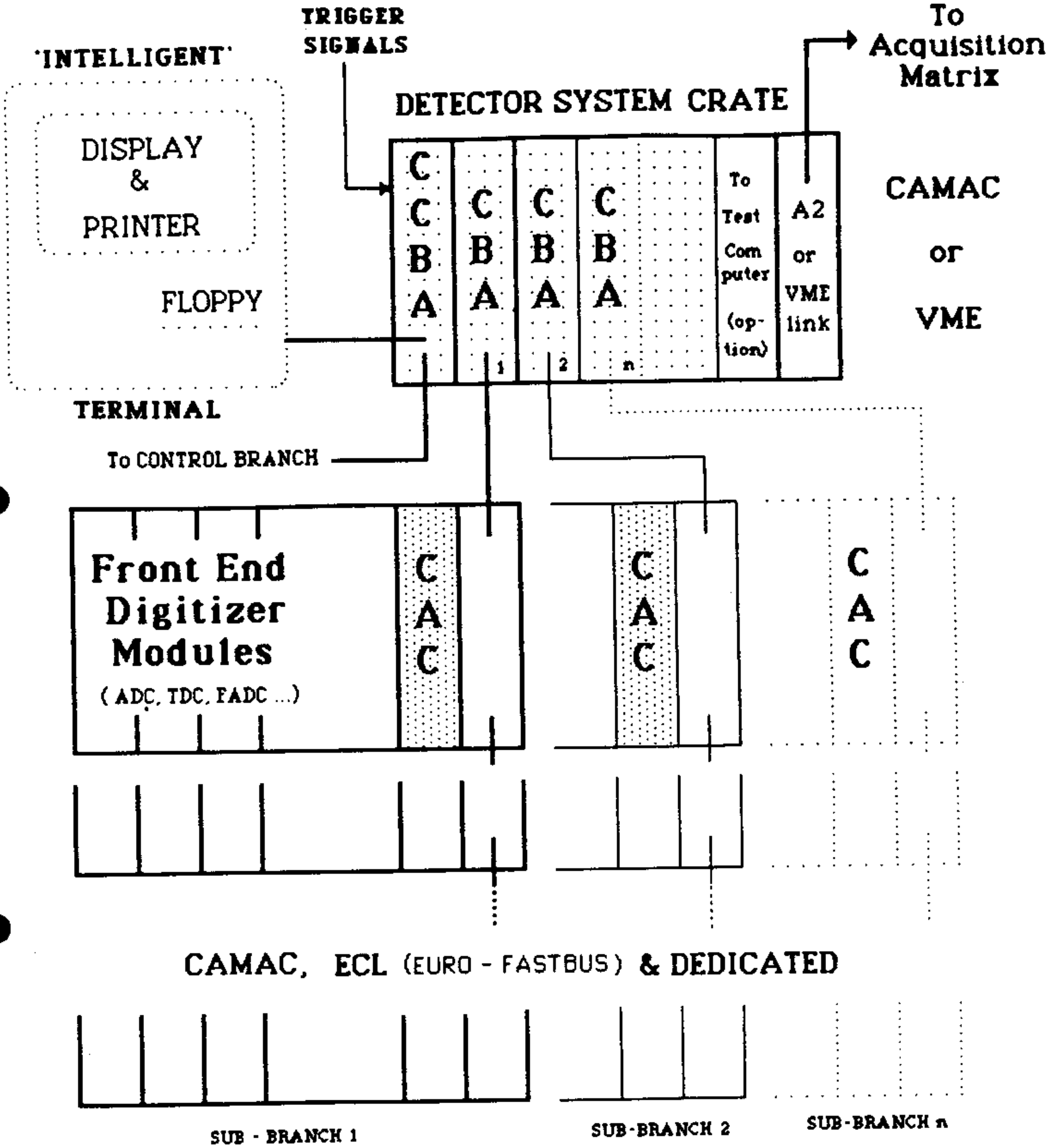

EVENT PROCESS
LEVEL 3
Complete reconstruction of
selected events
with 68020 processors or emulators
FILTER
(1 sec)
LEVEL 2
Simple software rejection using
digitized data
with CAC, CBA & FIF processors
TRIGGER
(18 microsec.)
LEVEL 1
(within bunch crossing)
Hardware decision using
direct analog signals
(energy sum, multiplicity, Z tracking, forward ....)
OPAL EVENT SELECTION

FIGURE 2



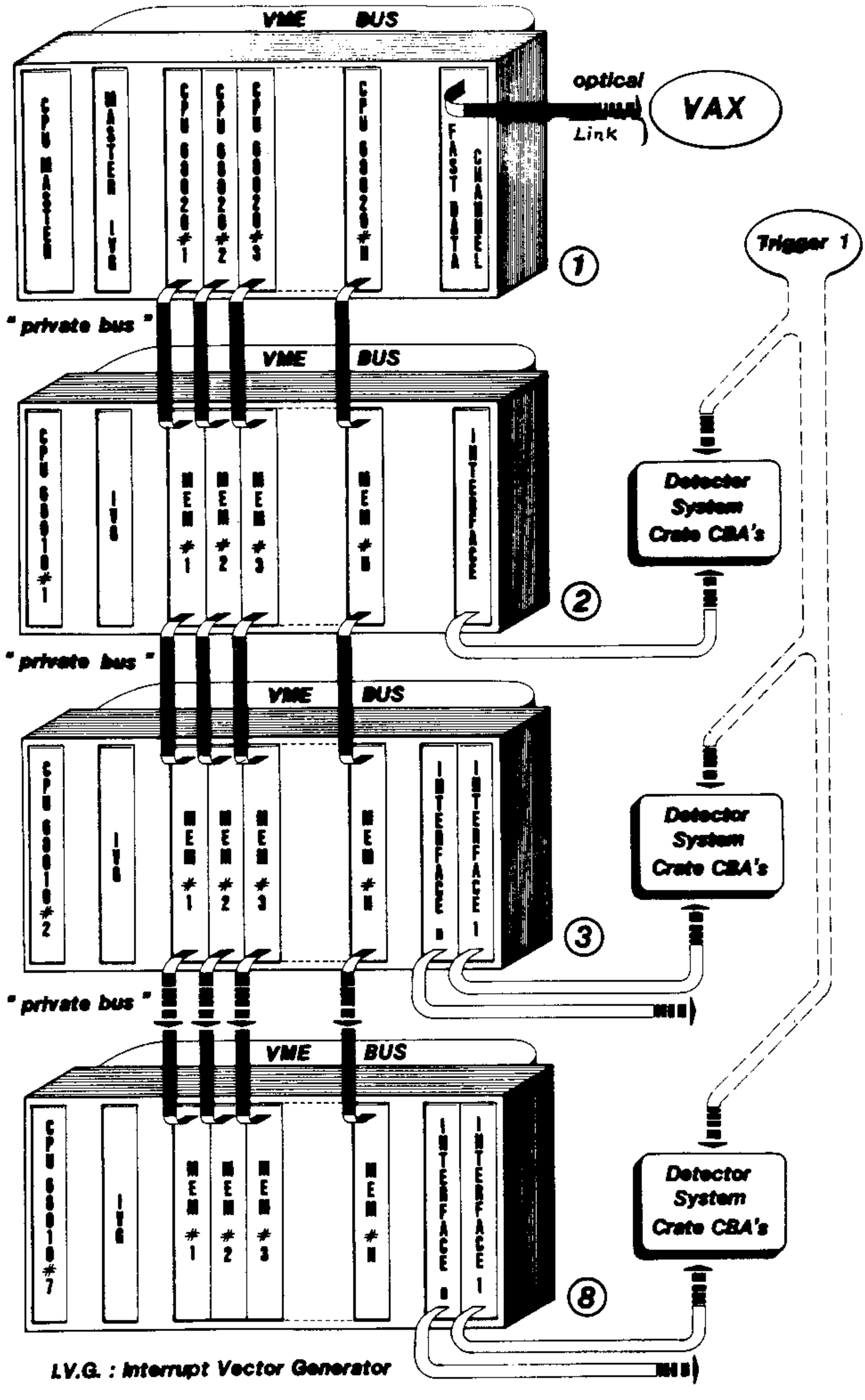
TRIGGER TIMING

FIGURE 3

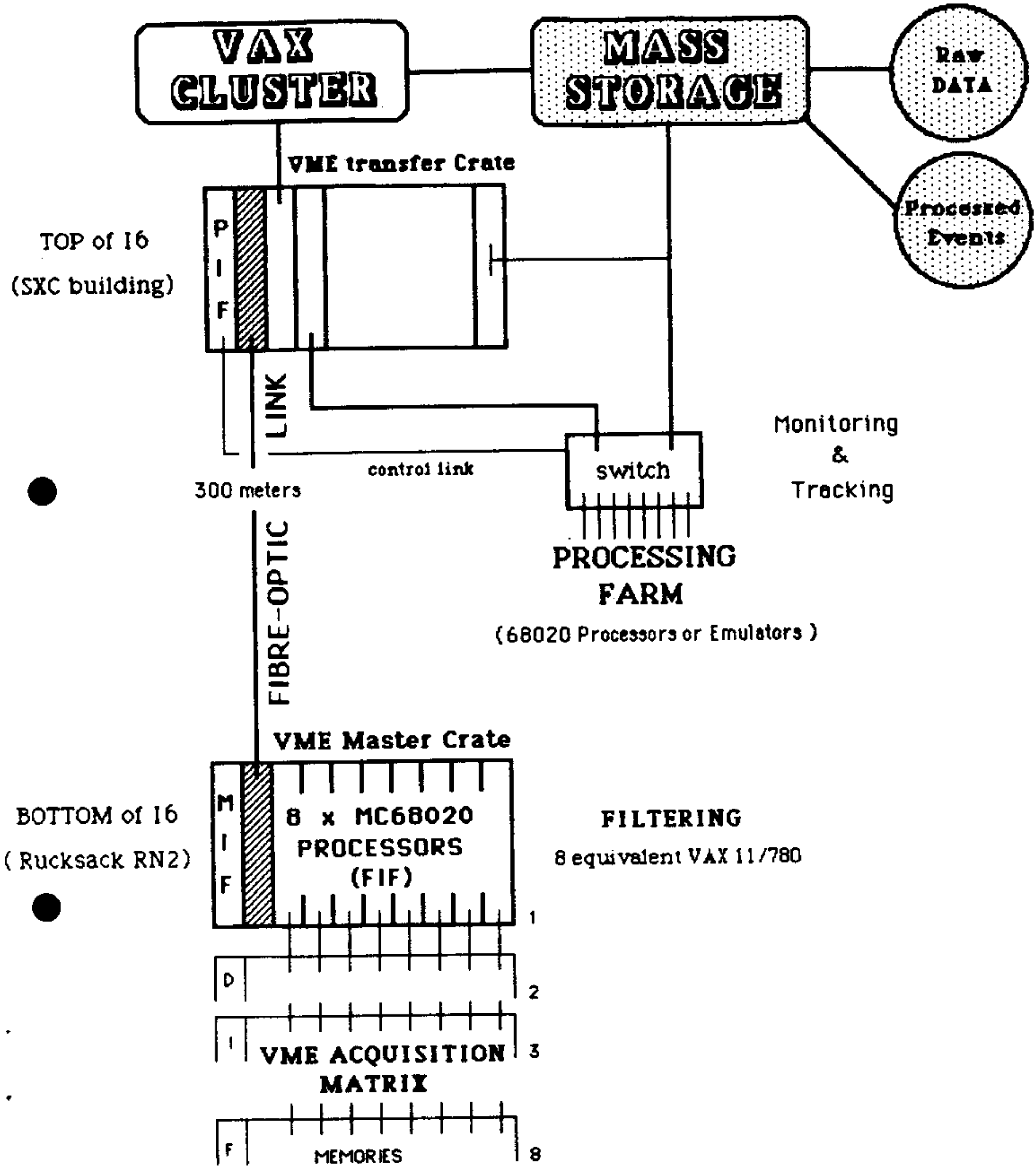


TYPICAL DETECTOR BRANCH

FIGURE 4

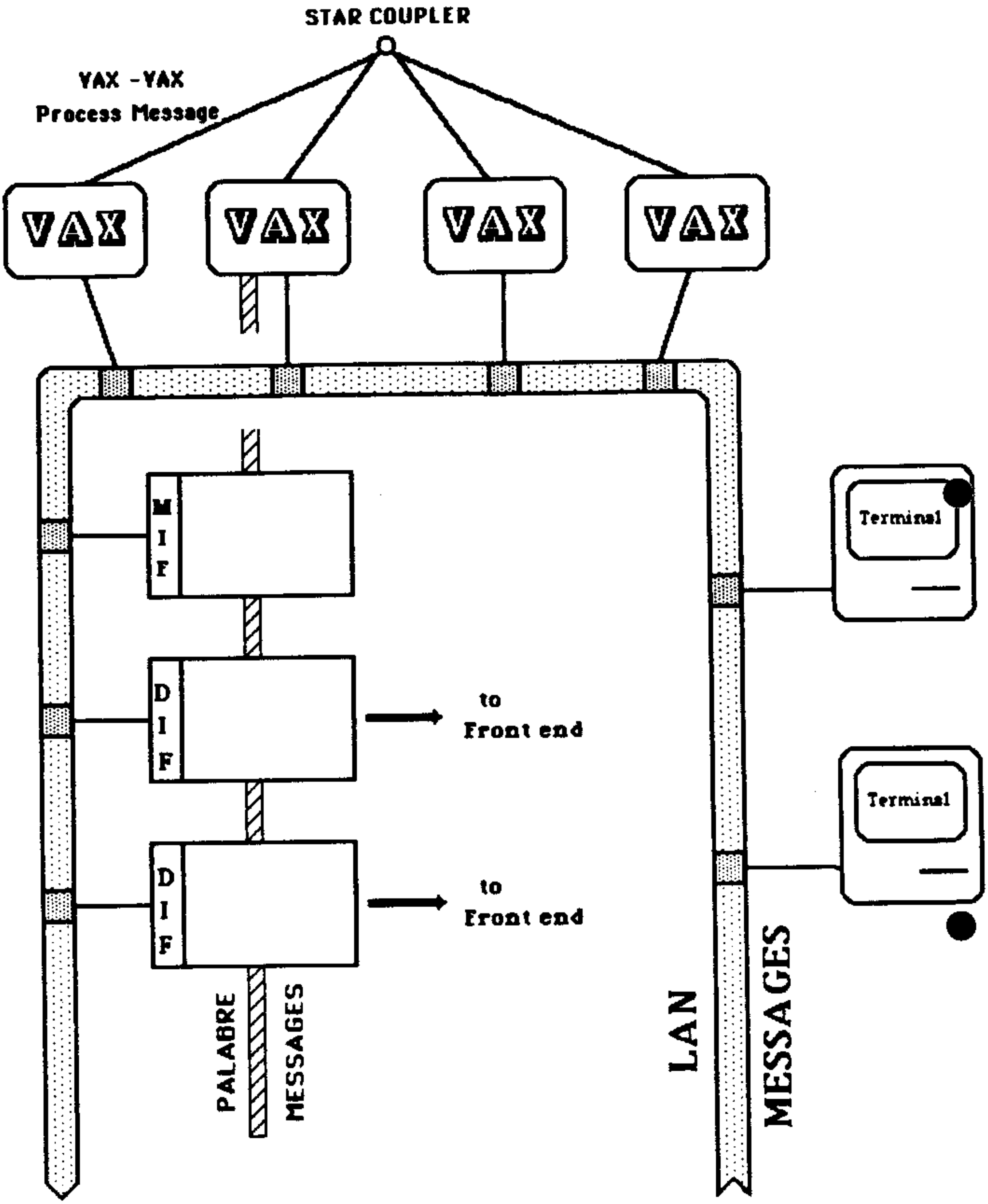


VME MATRIX INTERFACE



FINAL DATA COLLECTION & LINK TO SURFACE

FIGURE 6



OPAL Message Routing

FIGURE 7

APPENDIX 1

DETAILS OF THE OPAL

HARDWARE TRIGGER

APPENDIX I

FIRST LEVEL TRIGGER FOR OPAL

The first level trigger should be flexible enough to permit rapid and well documented changes according to the background conditions. Furthermore it should be general enough to permit the existence of various simultaneous redundant triggers for the same process in order to estimate the various efficiencies.

The OPAL detector, by having all its elements (particularly tracking detectors) providing signals within 15 μsec, may provide high quality, low background triggers within the bunch crossing interval.

The general philosophy of the first level trigger has been described in the main body of this report. The heart of this system is the so called trigger matrix box.

The trigger box will be composed of two distinct elements. One that correlates $\theta\phi$ information of various detector components (mainly central detector information with lead glass clusters and muon chambers) to provide input data to the second element on inclusive electron or muon candidates and colinear tracks and clusters. The second element is a matrix where the various trigger components are combined. Each element in the matrix is itself a programmable matrix where one can preset by the online computer the allowed combinations for the given running and background conditions. This will permit the writing of a record of the allowed trigger combinations for each run, making the bookeeping easier for the off-line analysis.

The schematics of this second element in the trigger matrix are given in Fig. 1. Each of the programmable active submatrices is represented by a small box. As can be seen, this system has a large degree of flexibility and also permits a good degree of redundancy. To show this property, Table I gives a set of reactions with the various triggers that will be activated. If some of the primary triggers (i.e. triggers that do not include combine requirements) would be deactivated due to backgrounds, still a large number of combined triggers will provide the needed redundancy.

FIG. 1

TRIGGER MATRIX

Schematics of the trigger matrix which combines the various trigger inputs delivered by the different subtrigger groups. Each small box represents a programmable submatrix.

	Test triggers	CD + TOF	E.M. det.	Had. cal.	FWD det.	Electrons	Muons	Quark
		0 tracks collinear tracks various track count. thresholds	energy sum levels collinear clusters various clusters count. thresholds	energy sum levels various clusters count. thresholds	Bhabhas 1 tag. 2 tag.	≥ 1 e ≥ 2 e	≥ 1 μ ≥ 2 μ	≥ 1 $q_{cand.}$ ≥ 2 $q_{cand.}$
No requirements	□	□	□	□	□	□	□	□
CD + TOF trig.		□	□	□	□	□	□	□
E.M. det. trig.			□	□	□	□	□	□
Had. cal. trig.				□	□	□	□	□
FWD det. trig.						□	□	□
Electrons							□	□
Muons								□

TABLE I

Example of physical processes and the activated trigger

PROCESS	TRIGGERS
$e^+e^- \to e^+e^-$	collinear tracks ≥ 2 tracks collinear E.M. clusters ≥ 2 E.M. clusters energy sum_1 in E.M. calorimeter ≥ 2 electrons ≥ 1 E.M. cluster + ≥ 1 track energy sum_2 in E.M. cluster + ≥ 1 track ≥ 1 electron + ≥ 1 track energy sum_2 in E.M. + ≥ 1 E.M. cluster ≥ 1 electron + ≥ 1 E.M. cluster Forward direction : Bhabhas
$e^+e^- \to \mu^+\mu^-$	collinear tracks ≥ 2 tracks collinear hadronic cluster ≥ 2 hadron clusters energy sum_1 in hadron calorimeter ≥ 2 muons ≥ 1 hadron cluster + ≥ 1 track ≥ 1 muon + ≥ 1 track ≥ energy sum_2 in had. cal. + ≥ 1 had. cluster ≥ 1 had. cluster + ≥ 1 muon ≥ energy sum_2 in hadron cal. + 1 muon
$e^+e^- \to$ multihadrons (2 jets)	collinear tracks ≥ 2 tracks ≥ 3 tracks, etc. collinear E.M. clusters ≥ 2 E.M. clusters energy sum_1 in E.M. calorimeter energy sum_1 in hadron calorimeter collinear cluster in hadron calorimeter ≥ 2 hadron clusters ≥ 2 electrons ≥ 1 track + ≥ 1 E.M. cluster ≥ track + energy sum_2 in E.M. calorimeter ≥ 1 track + ≥ 1 hadron cluster ≥ 1 track + energy sum_2 in had. cal. ≥ 1 track + ≥ 1 electron energy sum_2 in E.M. + ≥ 1 E.M. cluster ≥ 1 E.M. cluster + ≥ 1 hadron cluster energy sum_2 in E.M. + energy sum_2 in hadron calorimeter ≥ 1 E.M. cluster + ≥ 1 electron energy sum_2 in had. cal. + 1 hadron cluster energy sum_2 in had. cal. + 1 electron

	≥ 2 tracks
$e^+e^- \to s_\tau s_\tau$	≥ 1 electron
	≥ 1 muon
$\tilde{\gamma}\tau$	≥ 1 track + ≥ 1 E.M. cluster
$\tilde{\gamma}\tau$ $\mu\nu\bar{\nu}$	≥ 1 track + ≥ 1 hadron cluster
	≥ 1 track + ≥ 1 electron
$e\nu\bar{\nu}$	≥ 1 track + ≥ 1 muon
	≥ 1 E.M. cluster + ≥ 1 hadron cluster
	≥ 1 E.M. cluster + ≥ 1 muon
	≥ 1 electron + 1 muon
$e^+e^- \to \gamma\nu\bar{\nu}$	0 tracks with few hits + 1 E.M. cluster
	0 tracks with few hits + energy sum_2 in E.M. detector

APPENDIX 2

OPAL DATA COLLECTION

DETAILED DIAGRAMS OF THE 12 DETECTOR BRANCHES

VERTEX CHAMBER

JET CHAMBER

ZED CHAMBER

TIME OF FLIGHT

ELECTROMAGNETIC PRESAMPLER

ELECTROMAGNETIC BARREL CALORIMETER

HADRON CALORIMETER

MUON BARREL CHAMBERS

ELECTROMAGNETIC END CAP CALORIMETER

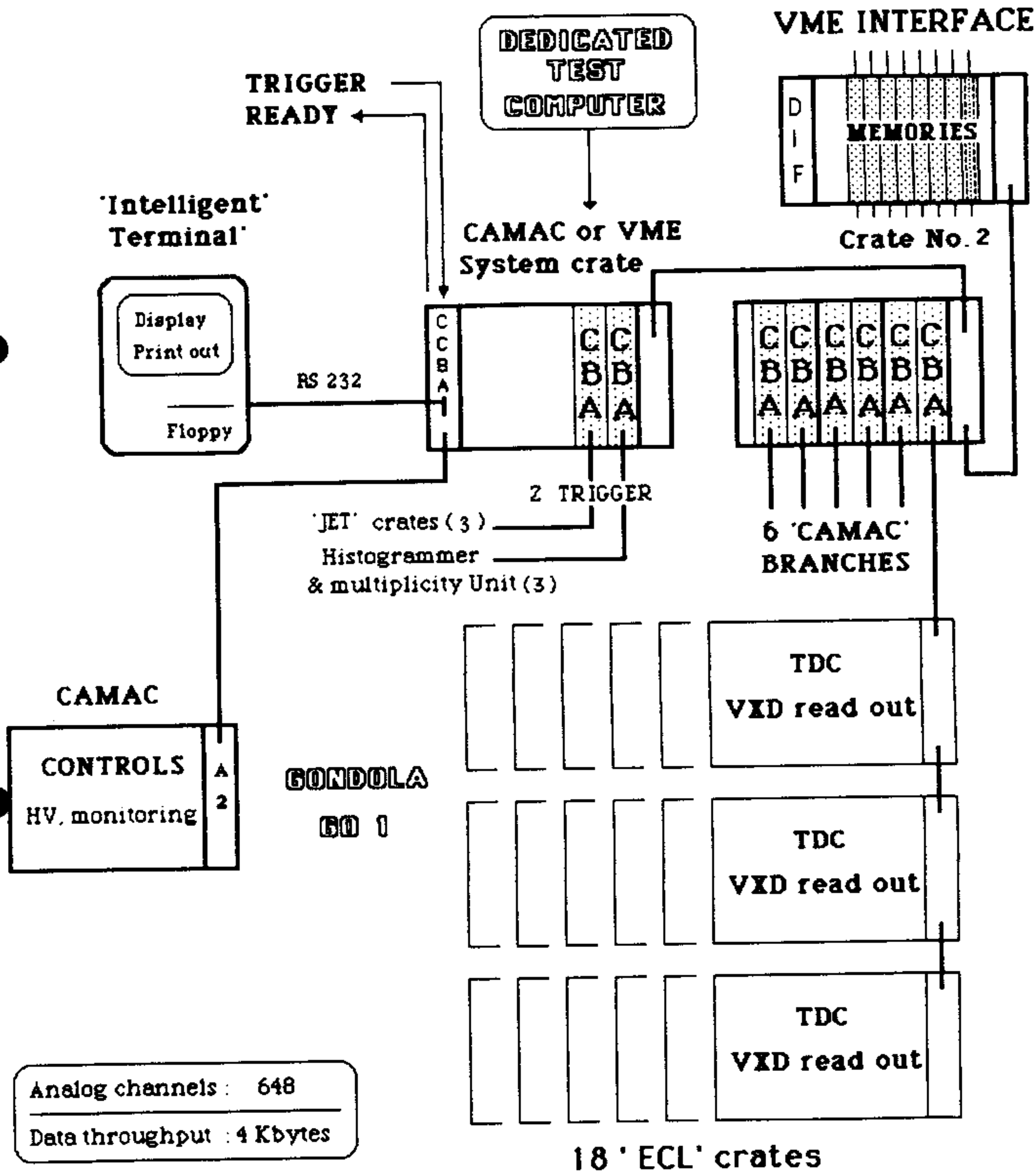
HADRON POLE TIP CALORIMETER

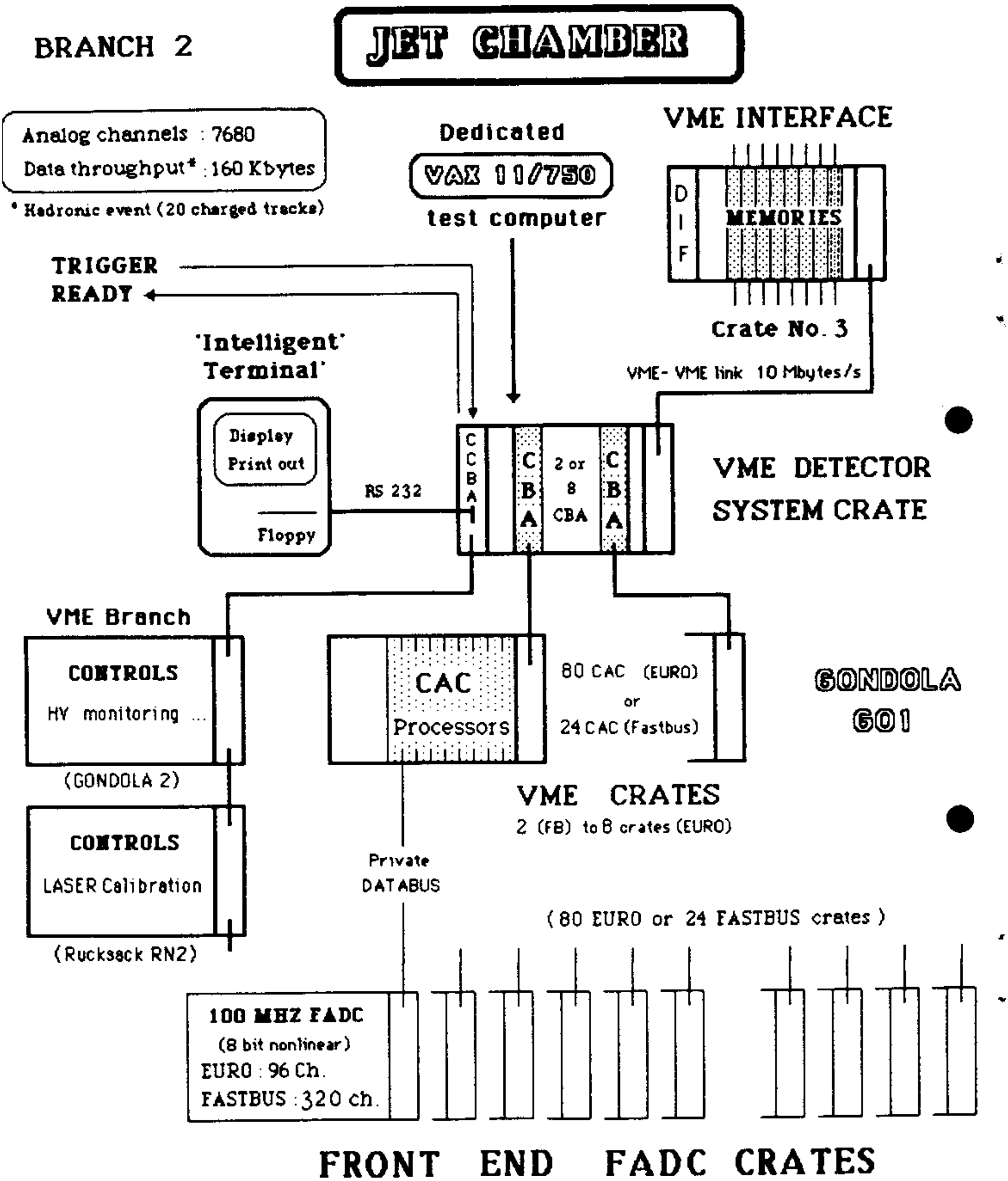
MUON END CAP CHAMBERS

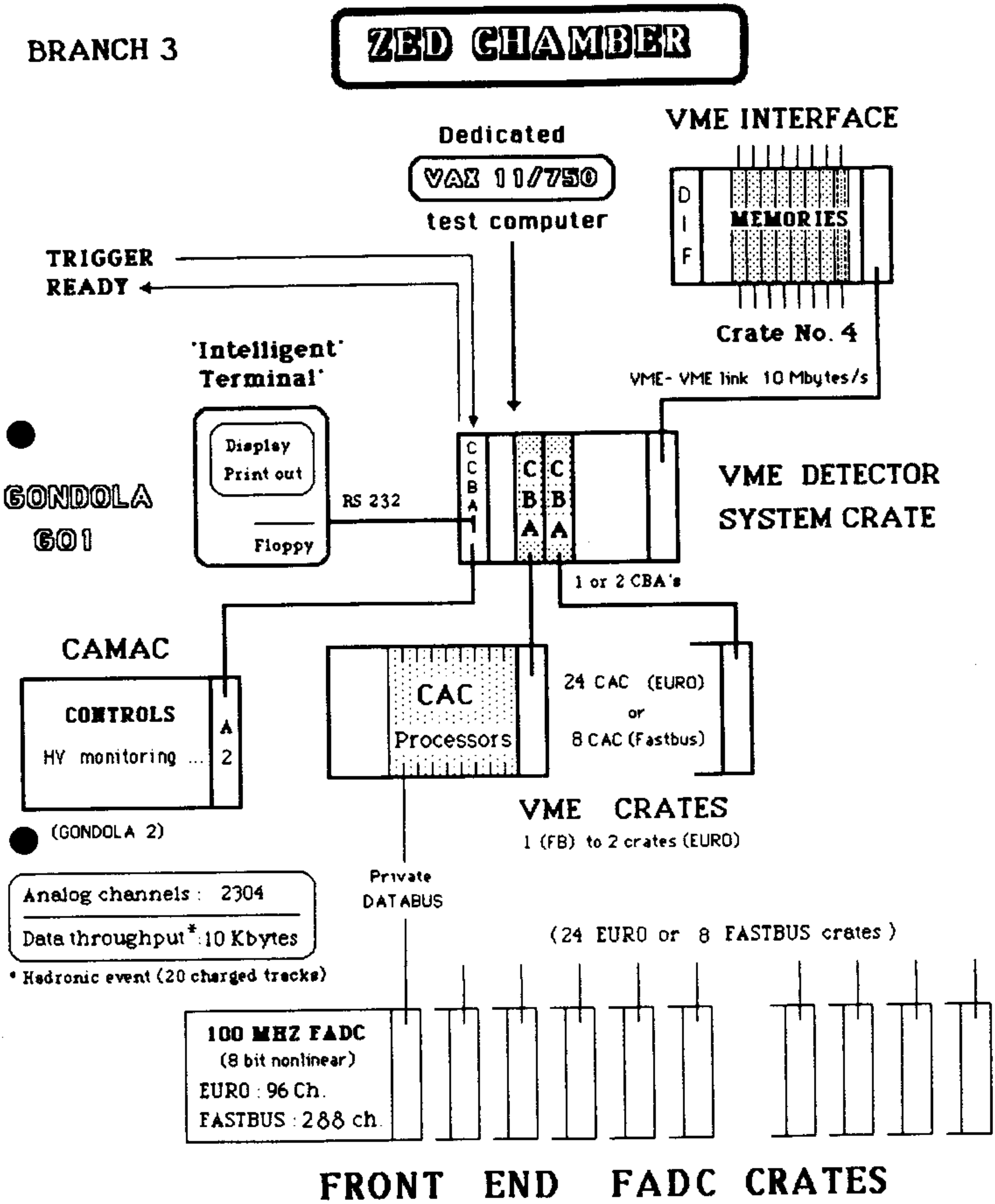
FORWARD DETECTOR

BRANCH 1

VERTEX CHAMBER



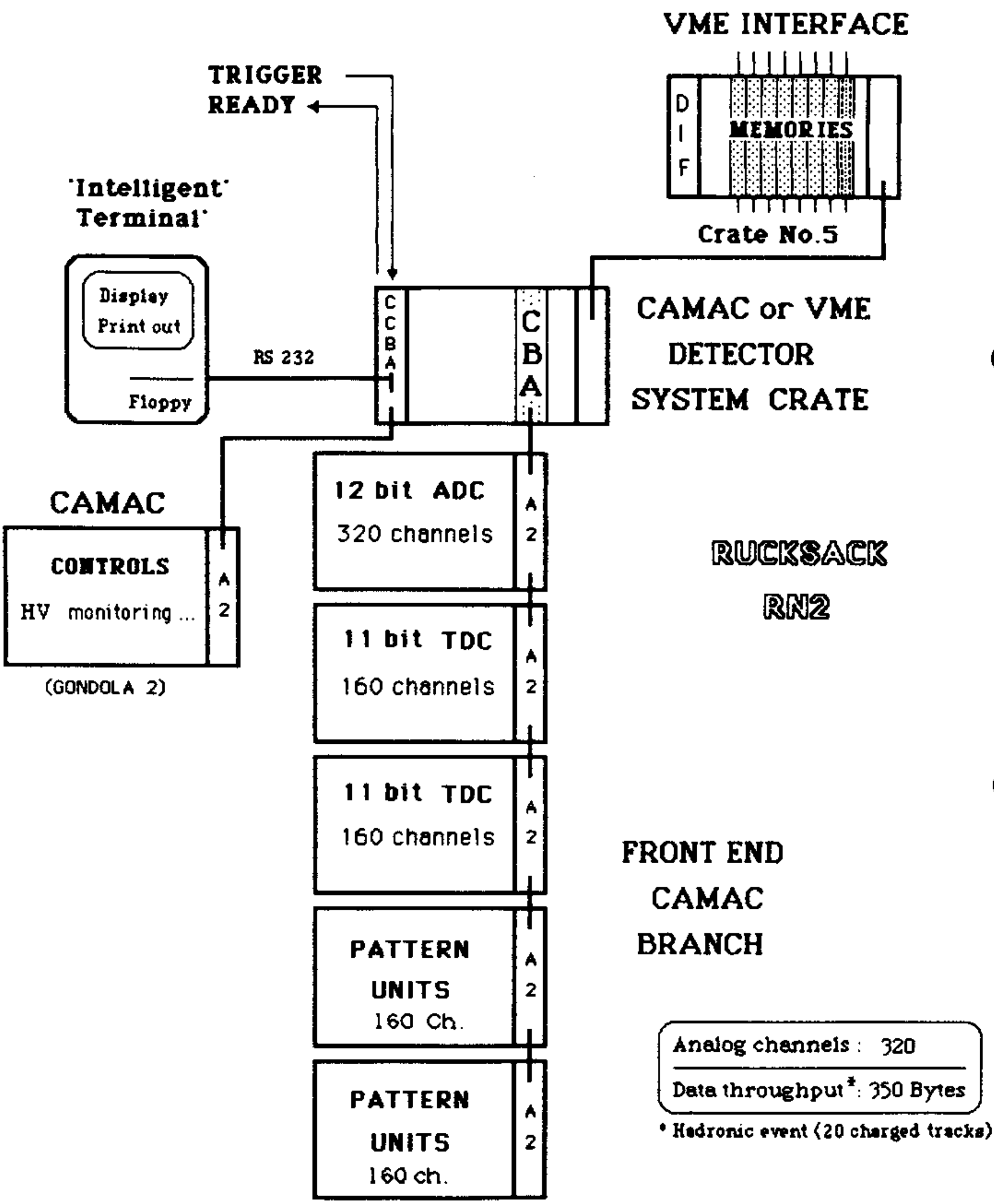

BRANCH 2
JET CHAMBER
Analog channels : 7680
Data throughput* : 160 Kbytes
* Hadronic event (20 charged tracks)
Dedicated
VAX 11/750
test computer
VME INTERFACE
D I F
MEMORIES
Crate No. 3
TRIGGER
READY
'Intelligent' Terminal'
Display
Print out
Floppy
RS 232
VME- VME link 10 Mbytes/s
CCBA
CBA
2 or 8 CBA
CBA
VME DETECTOR SYSTEM CRATE
VME Branch
CONTROLS
HV monitoring ...
(GONDOLA 2)
CONTROLS
LASER Calibration
(Rucksack RN2)
CAC
Processors
80 CAC (EURO)
or
24 CAC (Fastbus)
GONDOLA
601
VME CRATES
2 (FB) to 8 crates (EURO)
Private
DATABUS
(80 EURO or 24 FASTBUS crates)
100 MHZ FADC
(8 bit nonlinear)
EURO : 96 Ch.
FASTBUS : 320 ch.
FRONT END FADC CRATES

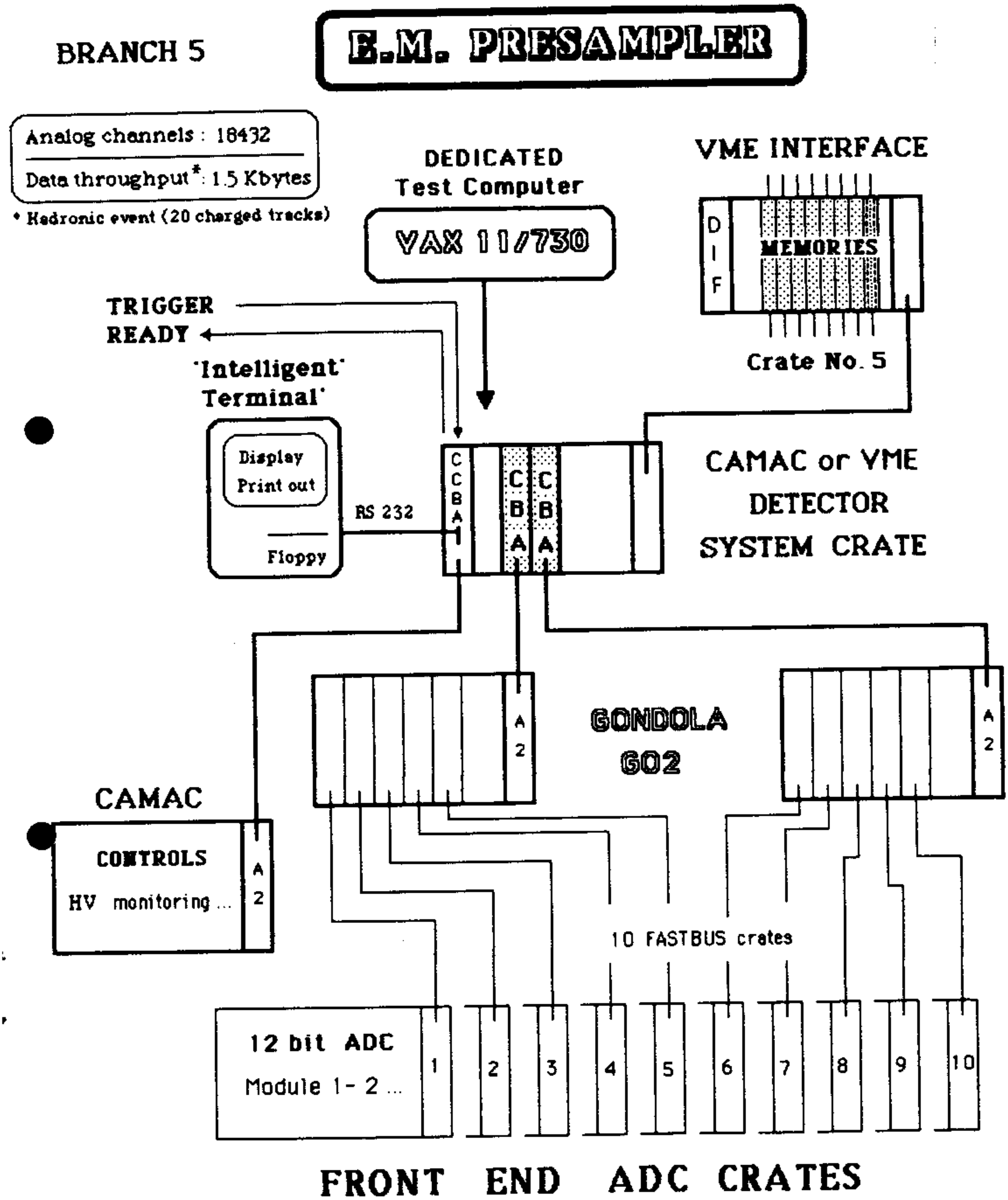


BRANCH 3
ZED CHAMBER
Dedicated
VAX 11/750
test computer
VME INTERFACE
D I F
MEMORIES
Crate No. 4
VME- VME link 10 Mbytes/s
TRIGGER
READY
'Intelligent'
Terminal'
Display
Print out
Floppy
RS 232
C C B A
C B A
C B A
VME DETECTOR
SYSTEM CRATE
1 or 2 CBA's
GONDOLA
601
CAMAC
CONTROLS
HV monitoring ...
A 2
(GONDOLA 2)
CAC
Processors
24 CAC (EURO)
or
8 CAC (Fastbus)
VME CRATES
1 (FB) to 2 crates (EURO)
Analog channels : 2304
Data throughput*: 10 Kbytes
* Hadronic event (20 charged tracks)
Private
DATABUS
(24 EURO or 8 FASTBUS crates)
100 MHZ FADC
(8 bit nonlinear)
EURO : 96 Ch.
FASTBUS : 288 ch.
FRONT END FADC CRATES

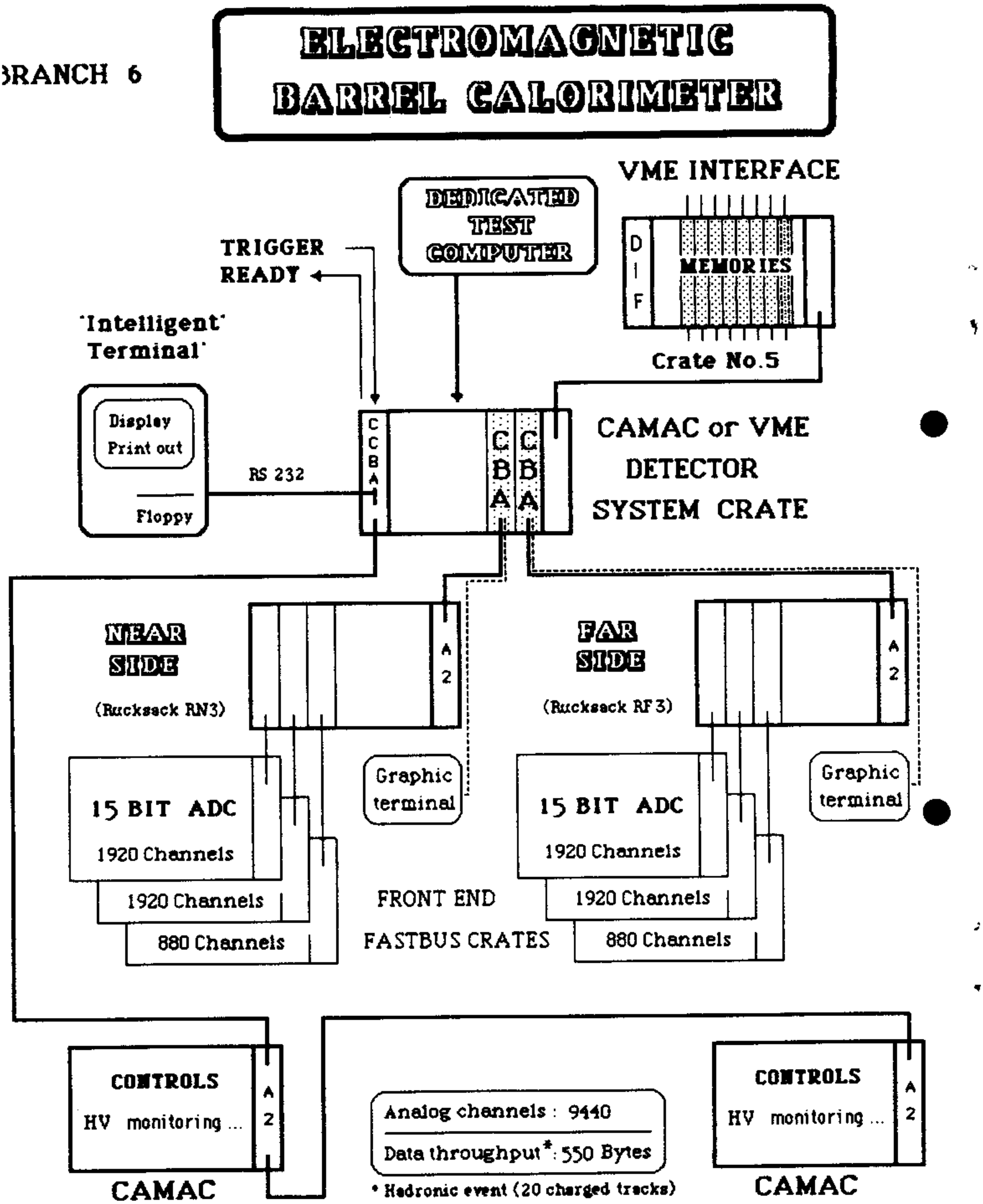
BRANCH 4

TIME OF FLIGHT

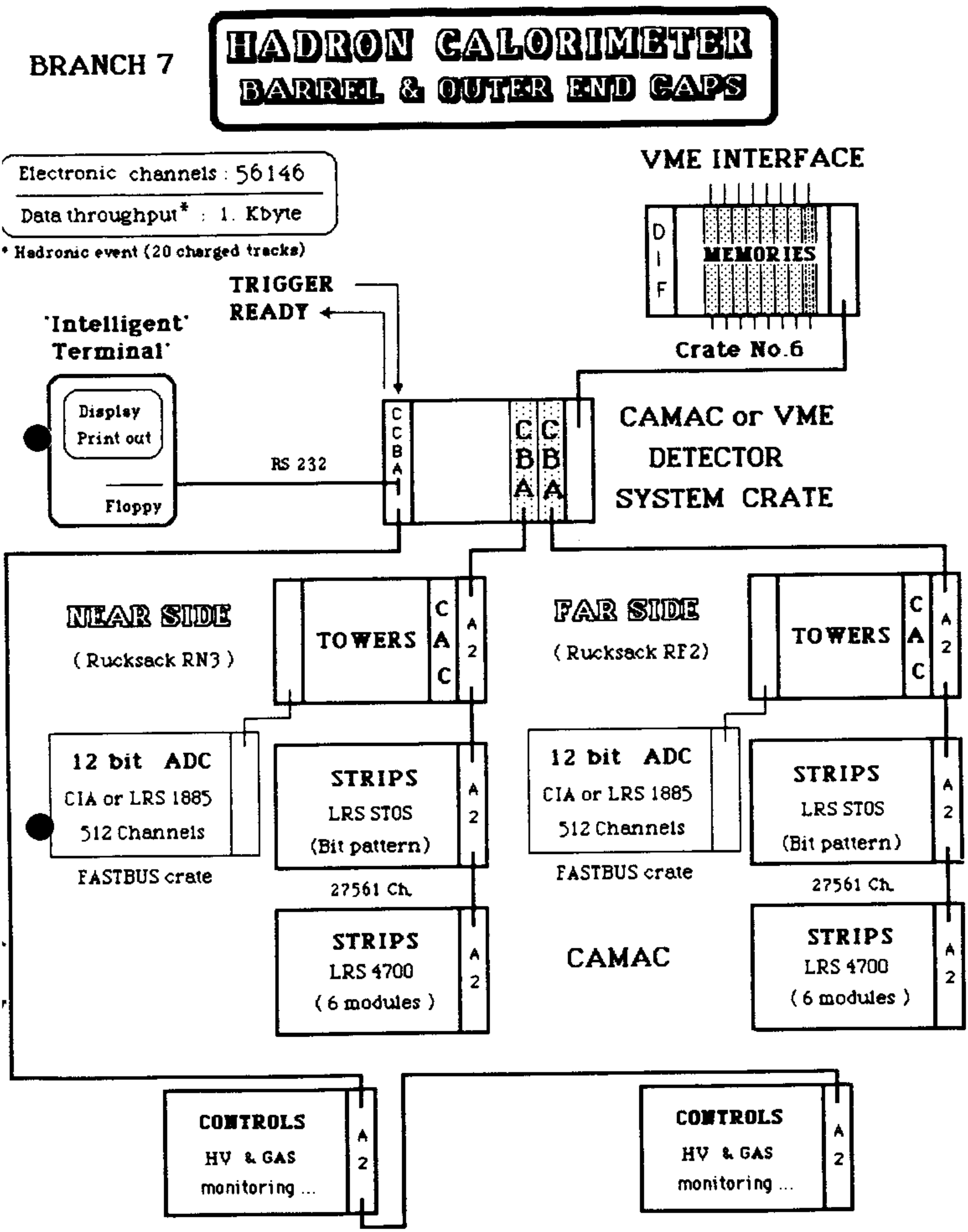



BRANCH 5
E.M. PRESAMPLER
Analog channels : 18432
Data throughput*: 1.5 Kbytes
* Hadronic event (20 charged tracks)
DEDICATED
Test Computer
VAX 11/730
VME INTERFACE
D I F
MEMORIES
Crate No. 5
TRIGGER
READY
'Intelligent'
Terminal'
Display
Print out
Floppy
RS 232
C C B A
C B A
C B A
CAMAC or VME
DETECTOR
SYSTEM CRATE
A 2
GONDOLA
G02
A 2
CAMAC
CONTROLS
HV monitoring ...
A 2
10 FASTBUS crates
12 bit ADC
Module 1 - 2 ...
1
2
3
4
5
6
7
8
9
10
FRONT END ADC CRATES

BRANCH 6



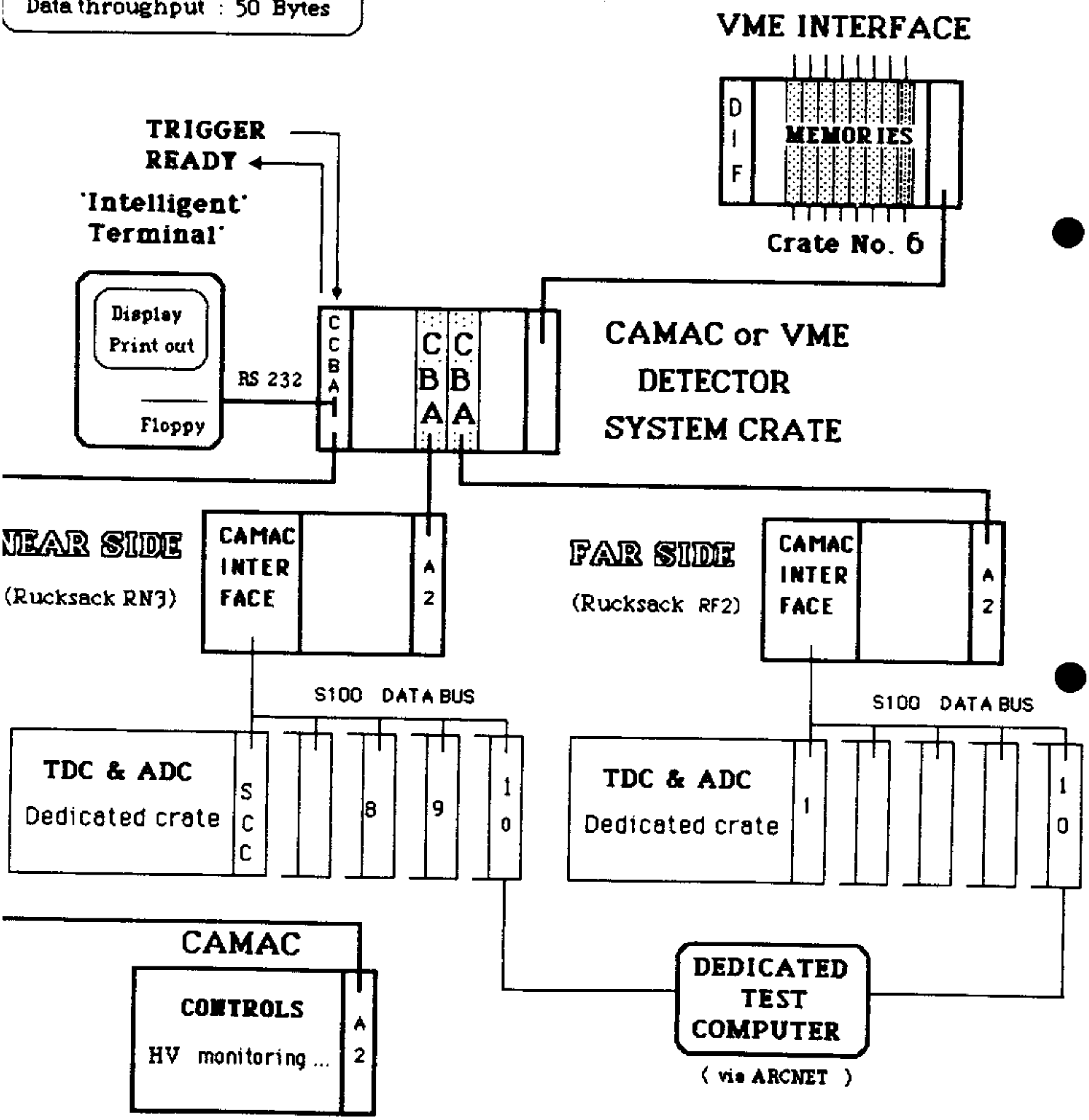
ELECTROMAGNETIC
BARREL CALORIMETER
VME INTERFACE
DEDICATED TEST COMPUTER
TRIGGER
READY
D I F
MEMORIES
Crate No.5
'Intelligent' Terminal'
Display
Print out
Floppy
RS 232
C C B A
C B A
C B A
CAMAC or VME
DETECTOR
SYSTEM CRATE
NEAR SIDE
(Rucksack RN3)
A 2
FAR SIDE
(Rucksack RF3)
A 2
Graphic terminal
15 BIT ADC
1920 Channels
1920 Channels
880 Channels
FRONT END
FASTBUS CRATES
Graphic terminal
15 BIT ADC
1920 Channels
1920 Channels
880 Channels
CONTROLS
HV monitoring ...
A 2
CAMAC
Analog channels : 9440
Data throughput*: 550 Bytes
* Hadronic event (20 charged tracks)
CONTROLS
HV monitoring ...
A 2
CAMAC


BRANCH 7
HADRON CALORIMETER
BARREL & OUTER END CAPS
Electronic channels : 56146
Data throughput* : 1. Kbyte
* Hadronic event (20 charged tracks)
VME INTERFACE
DIF
MEMORIES
Crate No.6
TRIGGER
READY
'Intelligent' Terminal'
Display
Print out
Floppy
RS 232
CCBA
CBA
CBA
CAMAC or VME
DETECTOR
SYSTEM CRATE
NEAR SIDE
(Rucksack RN3)
TOWERS
CAC
A2
FAR SIDE
(Rucksack RF2)
TOWERS
CAC
A2
12 bit ADC
CIA or LRS 1885
512 Channels
FASTBUS crate
STRIPS
LRS STOS
(Bit pattern)
A2
27561 Ch.
12 bit ADC
CIA or LRS 1885
512 Channels
FASTBUS crate
STRIPS
LRS STOS
(Bit pattern)
A2
27561 Ch.
STRIPS
LRS 4700
(6 modules)
A2
CAMAC
STRIPS
LRS 4700
(6 modules)
A2
CONTROLS
HV & GAS
monitoring ...
A2
CONTROLS
HV & GAS
monitoring ...
A2

BRANCH 8

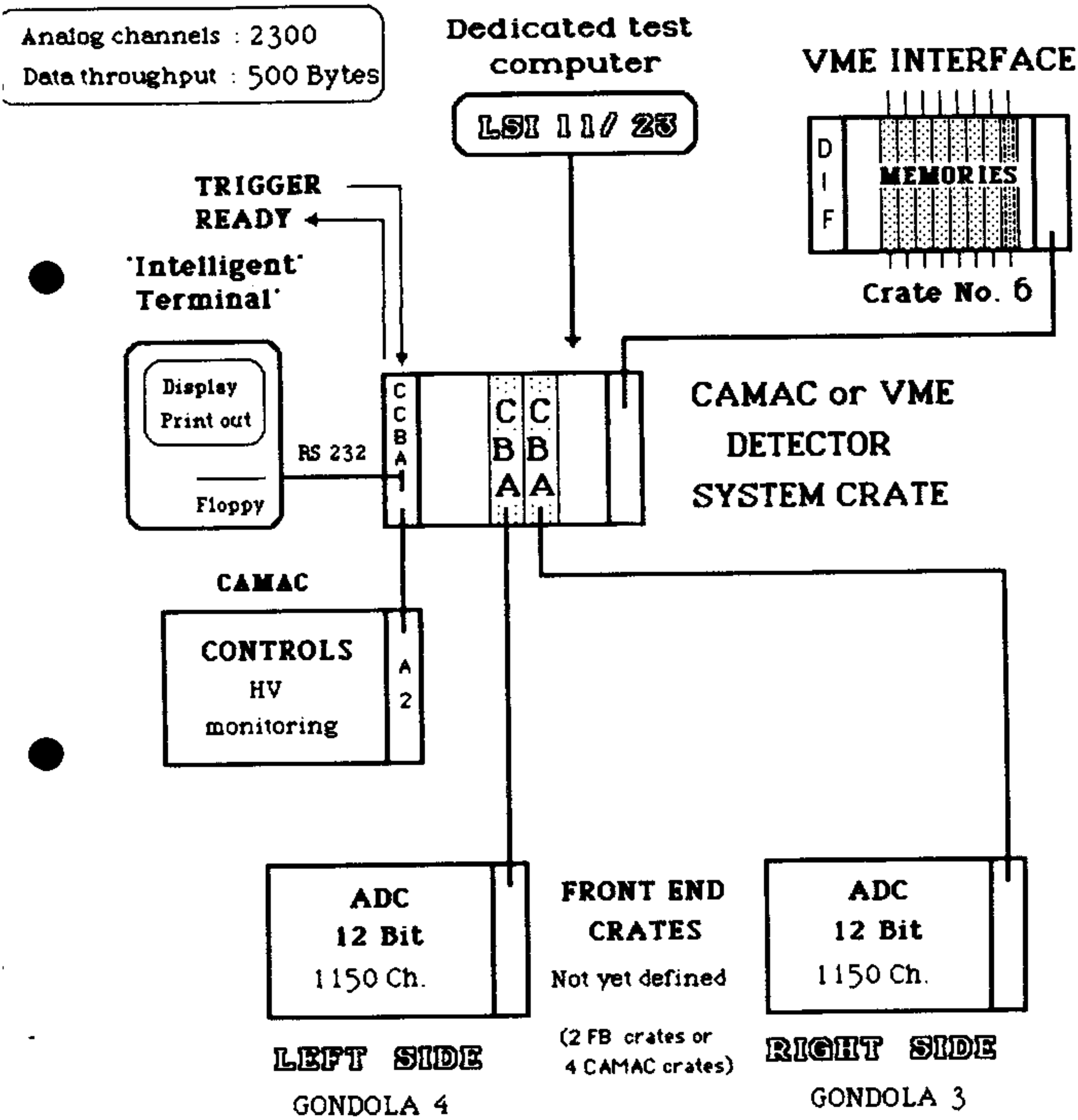
MUON BARREL CHAMBERS

Analog channels : 2240
Data throughput : 50 Bytes



BRANCH 9

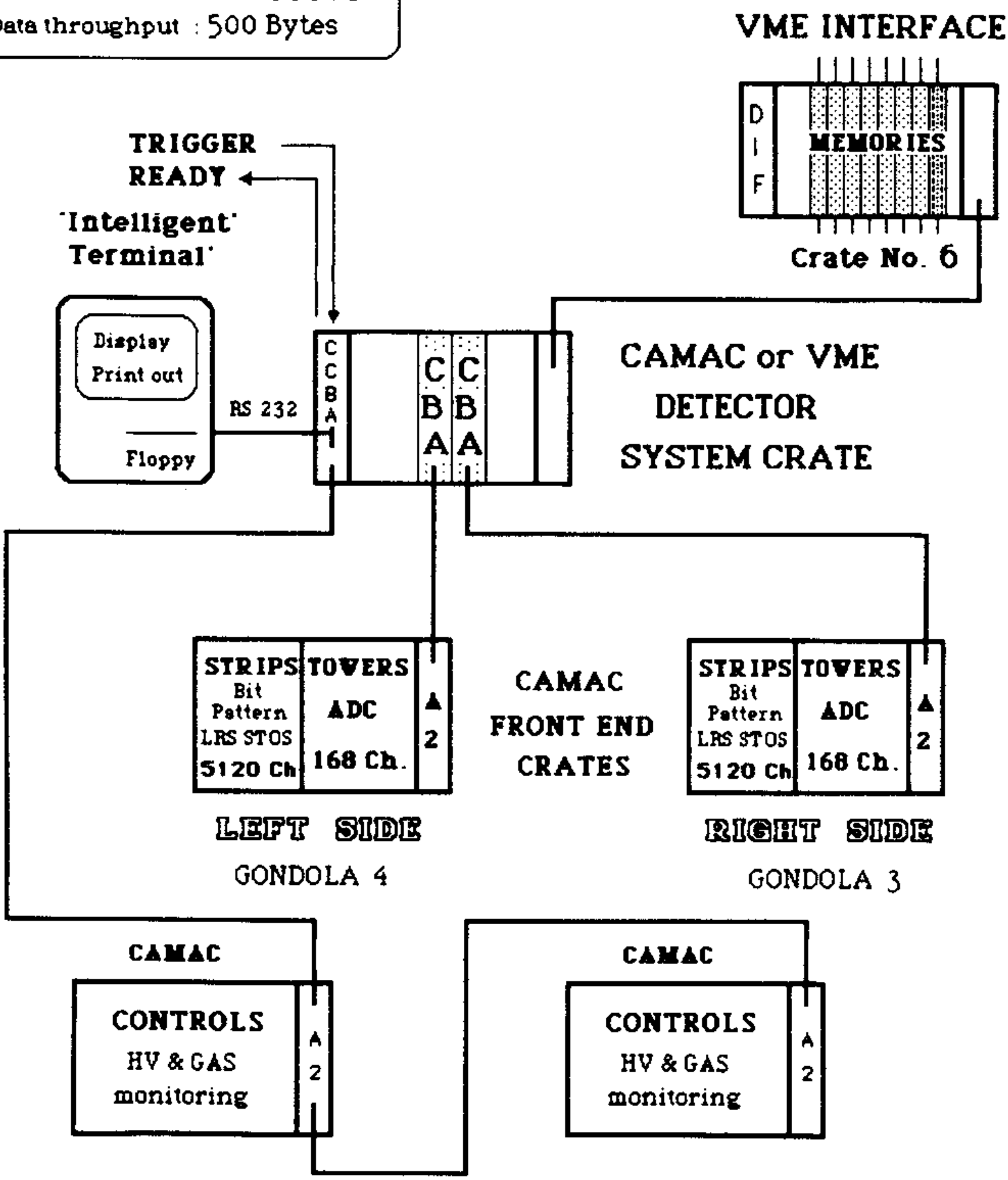
ELECTROMAGNETIC END CAP CALORIMETER



BRANCH 10

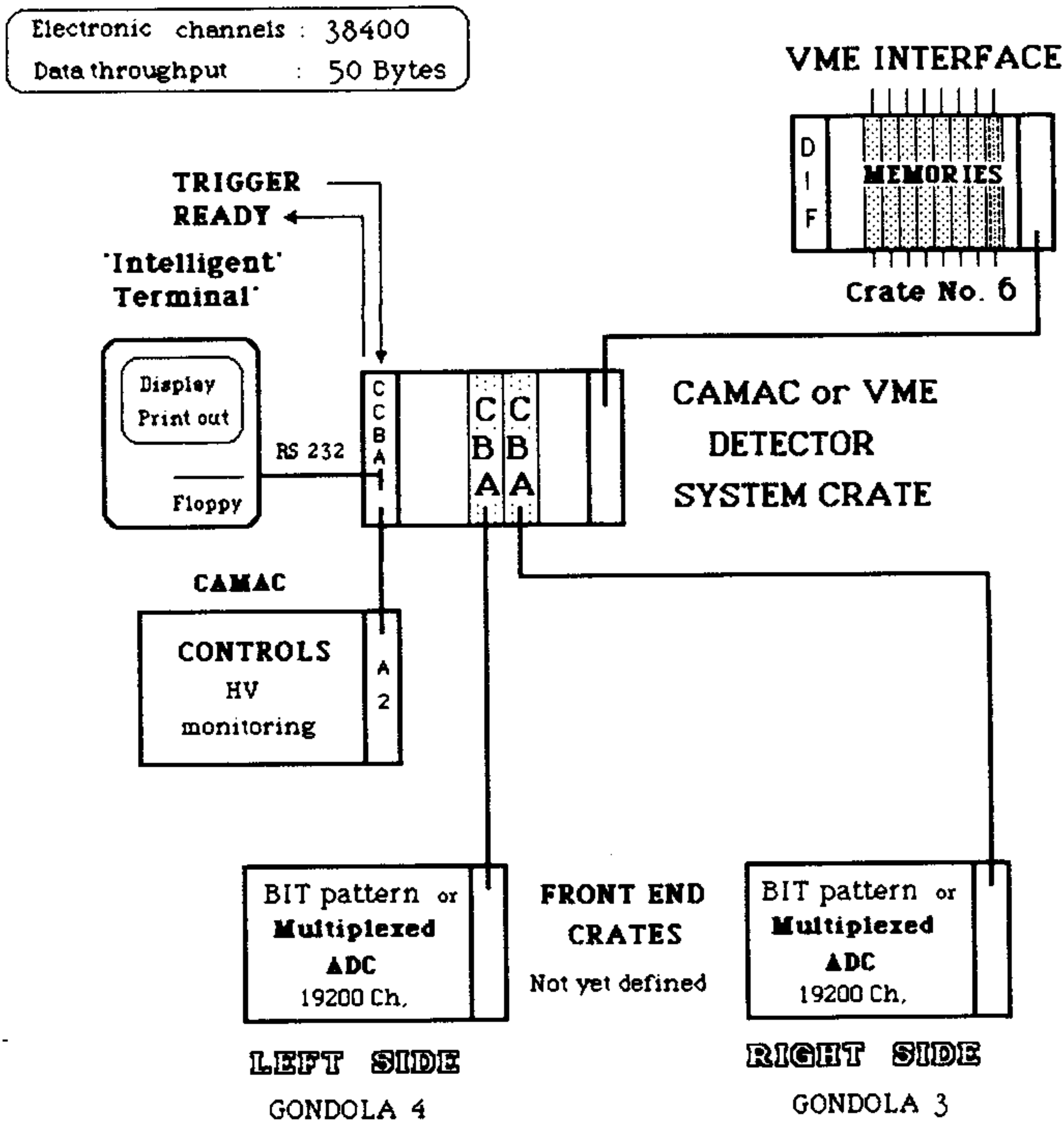
HADRON POLE TIP CALORIMETER

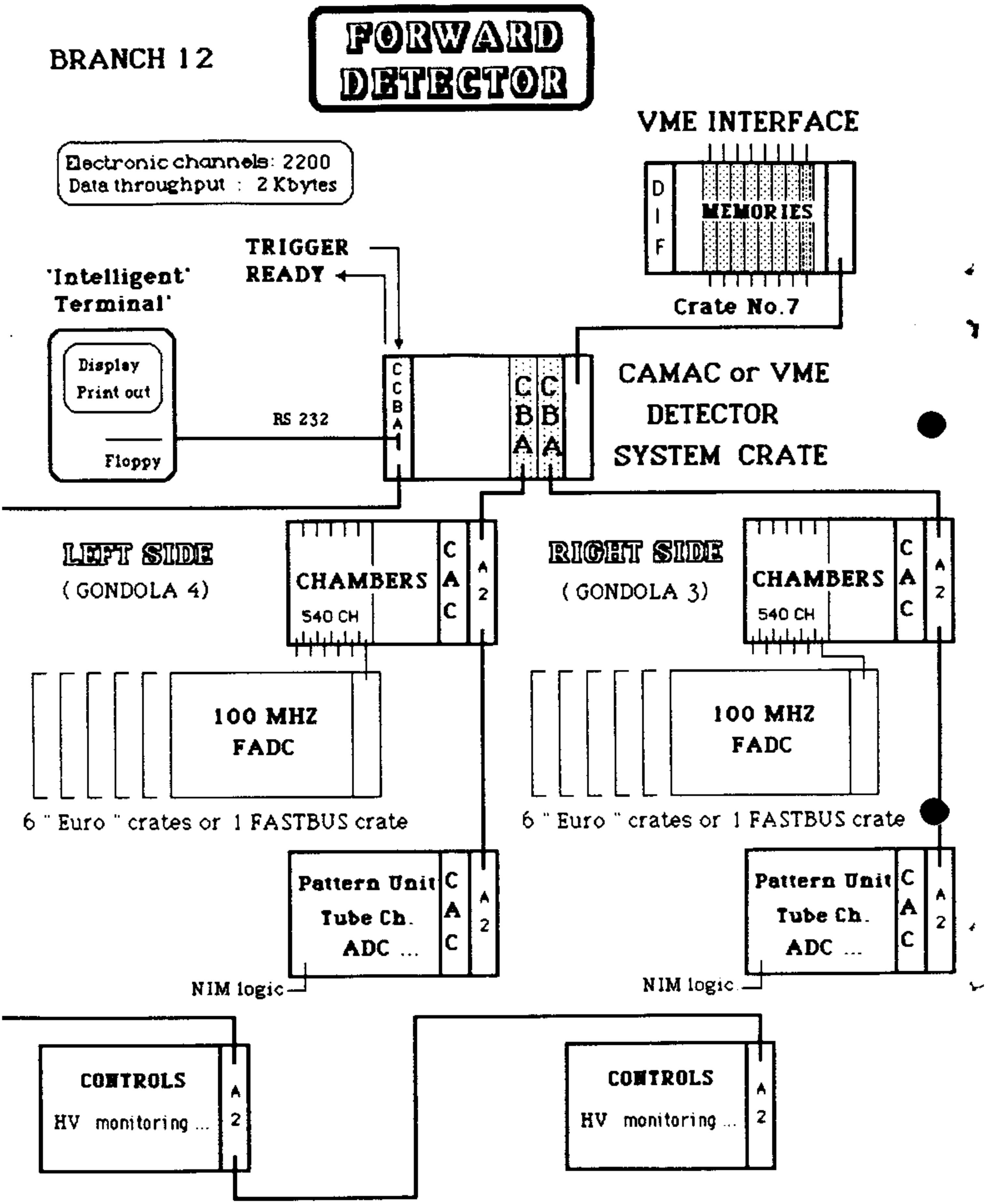
Electronic channels : 10576
Data throughput : 500 Bytes



BRANCH 11

MUON END CAP CHAMBERS





BRANCH 12
FORWARD DETECTOR
Electronic channels: 2200
Data throughput : 2 Kbytes
VME INTERFACE
DIF
MEMORIES
Crate No.7
TRIGGER
READY
'Intelligent' Terminal'
Display
Print out
Floppy
RS 232
CCBA
CBA
CBA
CAMAC or VME DETECTOR SYSTEM CRATE
LEFT SIDE
(GONDOLA 4)
CHAMBERS
540 CH
CAC
A2
RIGHT SIDE
(GONDOLA 3)
CHAMBERS
540 CH
CAC
A2
100 MHZ FADC
6 " Euro " crates or 1 FASTBUS crate
100 MHZ FADC
6 " Euro " crates or 1 FASTBUS crate
Pattern Unit
Tube Ch.
ADC ...
CAC
A2
NIM logic
Pattern Unit
Tube Ch.
ADC ...
CAC
A2
NIM logic
CONTROLS
HV monitoring ...
A2
CONTROLS
HV monitoring ...
A2

12/84 13.23.32 DSN=F22YAM.GCP.EE.COMP1
: 1 11 0 -32

$$\delta = \frac{136m}{Z^{1/3}E}\,\frac{\epsilon}{1-\epsilon}$$

all the other quantities have been described in the en

The kinematically allowed region for ϵ

$$\epsilon_c = \frac{k_c}{E} \le \epsilon \le 1 - \frac{m}{E} = \epsilon m$$

where, k_c is the photon cut off energy below which treated as a continuous energy loss (BCUTE in the p

The cross section [2] can be decomposed as i important!)

$$\frac{d\sigma}{d\epsilon} = \dots$$

where

α_1 =

α_2 =

$f_1(\epsilon)$ =

$f_2(\epsilon)$ =

$g_1(\epsilon)$ =

$g_2(\epsilon)$ =

DATA HANDLING DIVISION
DD/EE/84-1
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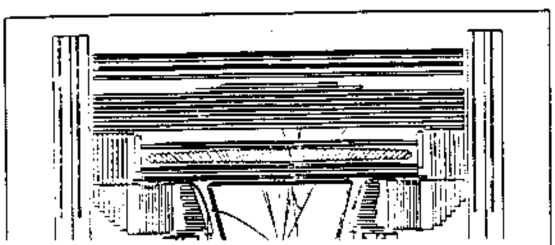
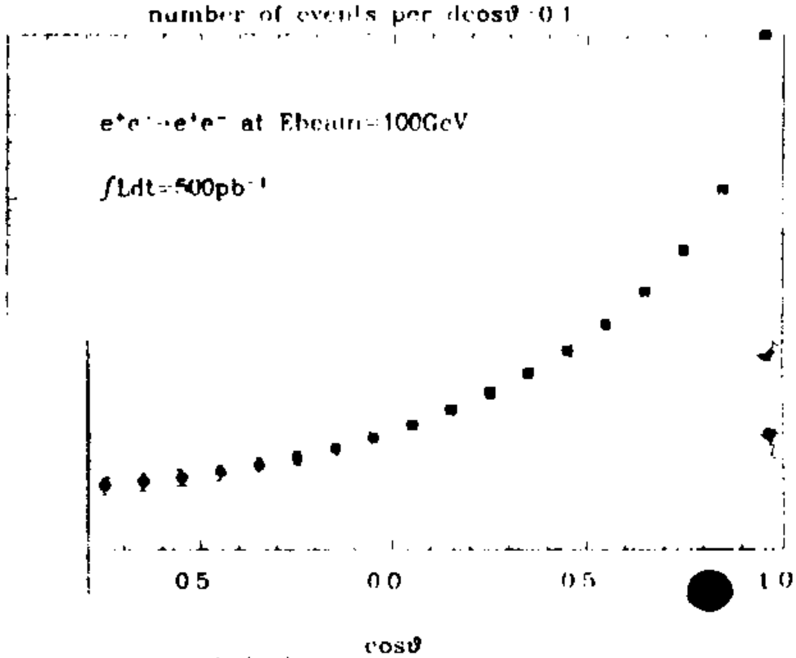
GEANT3
USERS GUIDE





IA COUNT(1/0.1)

ine material for G10 and H2O

```
SMIXT(26,'COIL G10$',AG10,ZG10,DENG10,NG10,WG10)
SMIXT(27,'     H2O$',AH2O,ZH2O,DENH2O,NH2O,WH2O)
```

ine tracking media for coils
if magnetic field within the coil material)

```
STMED(26,'COIL G10$',26,0,3,2,...)
STMED(26,'COIL ALS',9,0,3,2,...)
```

inition of the differents tubes

```
SVOLU('C1+ ','TUBE',26,PCOIL1,3,IVOL)
SVOLU('C2+ ','TUBE',26,PCOIL2,3,IVOL)
SVOLU('C3A+','TUBE',26,PCOI3A,3,IVOL)
SVOLU('C3B+','TUBE',27,PCOI3B,3,IVOL)
SVOLU('C3C+','TUBE',26,PCOI3C,3,IVOL)
SVOLU('C3D+','TUBE',26,PCOI3D,3,IVOL)
SVOLU('C4+ ','TUBE',26,PCOIL4,3,IVOL)
```

ition of level 1 volumes inside COI+

```
SPOS('C1+ ',1,'COI+',0.,0.,0.,0,'ONLY')
SPOS('C2+ ',1,'COI+',0.,0.,0.,0,'ONLY')
SPOS('C3+ ',1,'COI+',0.,0.,0.,0,'ONLY')
SPOS('C4+ ',1,'COI+',0.,0.,0.,0,'ONLY')
```

ition of level 2 volume inside level 1 volume

```
SPOS('C3A+',1,'C3+ ',0.,0.,0.,0,'ONLY')
SPOS('C3C+',1,'C3+ ',0.,0.,0.,0,'ONLY')
```

ition of level 3 volume inside level 2 volume

```
SPOS('C3B+',1,'C3A+',0.,0.,0.,0,'ONLY')
SPOS('C3D+',1,'C3C+',0.,0.,0.,0,'ONLY')

RETURN
END
```

09/08/