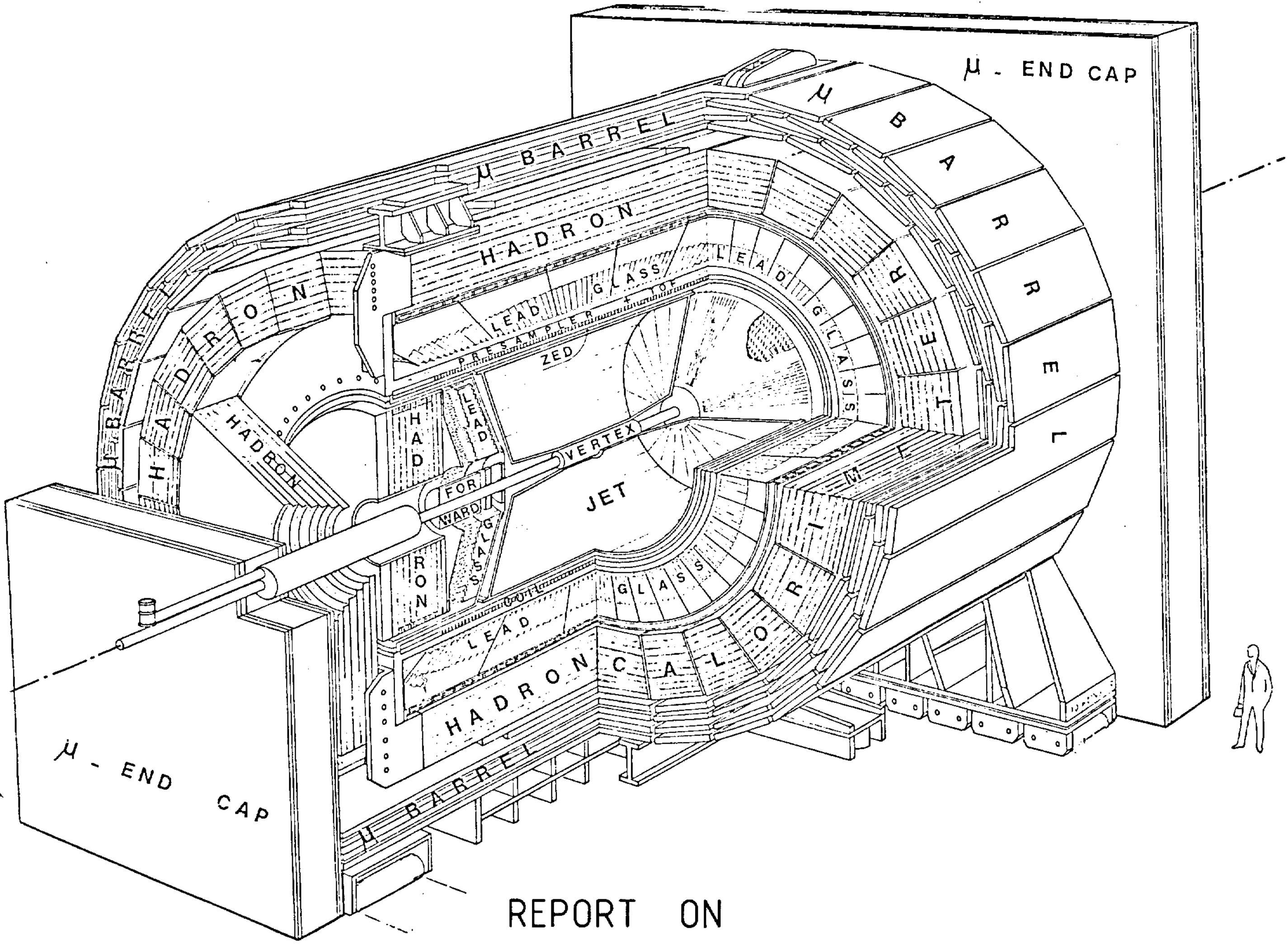
CERN/LEPC 84-2
LEPC/PR1 OPAL
19 January 1984

OPAL



REPORT ON

DATA ACQUISITION AND ANALYSIS

JANUARY 1984

CERN/LEPC 84-2
LEPC/PR1 OPAL
18 January 1984

OPAL DATA ACQUISITION AND ANALYSIS

TABLE OF CONTENTS Page

OPAL DATA ACQUISITION AND ANALYSIS

1. INTRODUCTION

The goal of the OPAL data handling group is to deliver, at LEP turn-on, a completely tested and debugged data acquisition and analysis package for rapid evaluation of physics results. This report details how this task will be accomplished.

The proposed data acquisition scheme is a multi-function system with distributed intelligence providing a variety of services in addition to the data gathering. The precise configuration is still under design and will continue to evolve as experience is gained in test prototypes and new data handling technologies become available.

Due to the complexity of the OPAL detector and the huge amount of data to be collected, the data acquisition system has to be simple, flexible and reliable. It is thus fundamental to use standard components wherever possible.

Data acquisition consists of a number of activities executed in parallel. It is the function of the back-end on-line software and hardware to ensure that these are performed in a controlled and orderly fashion. The activities include :

i) Collection and recording of data from the front-end microprocessor tree. The data are also disseminated to other processing systems which do not have direct access to the incoming data stream.

ii) Monitoring activities - including event data checking and histogram filling throughout the acquisition hardware.

iii) Extraction, transfer, and presentation of histogram and graphic information at operator terminals.

iv) Measurement and recording of all detector operating conditions (such as, for example, high voltages and trigger settings) and comparison of these with their nominal values.

v) Performing tests on all parts of the data acquisition hardware and software (processor memories and programs, bus structures, etc...). Because of the large number of units involved, such checks have to be made in a regular and systematic way.

vi) Collection of information for calculation of calibration constants (such as pedestals, for example), which can be done concurrently with data acquisition.

vii) Dialogue with the LEP machine network.

Much of the on-line filtering and monitoring software for the main data acquisition computers will be based on the more sophisticated off-line version. The same will be true for detector graphics applications. If data are recorded locally, tapes will be transported to the Computer Centre for rapid error detection and preliminary calculations.

Bulk data processing will be done initially at CERN and will utilize the central computers (including the proposed Tokyo main-frame) and banks of main-frame emulators. Physicists at Personal Workstations both at the intersection region (IR) and on the main CERN site must be able to run a multitude of analysis tasks with or without graphics. Parallel analysis will also be possible at those collaborating institutions with sufficient computing facilities.

Although much of the software will be developed within the collaboration outside CERN, the central base for on-line and off-line software testing/amalgamation/support/distribution/back-up will be at CERN itself. A team of resident software support professionals, augmented by visiting personnel, will perform this function. Close liaison will be maintained with corresponding CERN groups and other LEP teams to permit common solutions to common problems.

The following sections of this report briefly describe some of the considerations involved in the design of the OPAL data acquisition and analysis system, give a timetable for its development, estimate the CPU capacity required for data analysis, and list those services and facilities which will be required from CERN.

2. EXPERIENCE FROM OTHER EXPERIMENTS

Considerable experience has been accumulated in the last few years in the operation of detectors at PETRA. Much of this experience, particularly in the area of software, will be of value in achieving an optimum design for OPAL code. Considering the example of JADE, several features are worthy of note :

i) Current processing times for multi-hadron events average ≃ 1 sec. on an IBM 370/168. With the expected increase of track multiplicity at LEP and the significant increase in detector complexity (OPAL has roughly 4 times as many wires, Pb. Glass blocks, etc..), CPU time may be ≃ 20 sec/event.

ii) Modularity in the design of the off-line code has enabled very flexible processing easily controlled by a particular user.

iii) Nearly all programs have graphics versions in which most constants and limits can be easily (and interactively) changed. This graphics facility has enabled a) results to be displayed, especially from different analysis tasks, b) different detector parts to be viewed, c) particular regions to be viewed in detail, d) forward or backward track extrapolation, e) editing of events by typed corrections or the use of a joystick, etc..

iv) Remote data recording - in this case tape writing - is employed with success. The data link is reliable and it greatly reduces the workload in the local control room.

At CERN, experience is available with detectors which are of similar size and complexity to OPAL, namely, UA1 and UA2. This experience is useful in the design of the off-line software as well as the hardware and software of the on-line system. OPAL follows closely the developments, particularly at UA1, in these fields.

The most important lesson to be learned is not to underestimate the enormous effort in manpower needed to achieve a fully debugged and working system. An early beginning is essential, especially with Monte Carlo simulated data, so that major deficiencies can be isolated and remedied before real data are accumulated and the code frozen.

3. INPUT PARAMETERS

The peak cross section for the process $e^+e^- \rightarrow Z^0 \rightarrow \mu^+\mu^-$ is expected to be 1.4×10^{-33} cm^2 with $\sin^2\theta_W = 0.215$ [$M_Z = 93.7$ GeV, $\Gamma_Z = 3.0$ GeV] and radiative corrections neglected. The total cross section will be greater by the factor R_Q (= 24.2) for the production of 6 flavours of quark plus the factor R_L (= 9.1) for 3 generations of leptons, giving a total cross section of 45 nanobarns. 10 GeV away from the Z^o peak the cross-section drops dramatically to only a few percent of the peak value.

Assuming a time-averaged LEP luminosity of 0.5×10^{31} cm^{-2}sec^{-1} and 4000 scheduled data-taking hours per year at the Z^o peak, roughly 3.5 million Z^o events could be recorded. Realistically, during the first year or two of LEP operation, inefficiencies in both machine and detector operation will substantially reduce this rate. Nevertheless, our analysis system must be able to cope with this data rate.

The maximum trigger rate for OPAL will be 45,000 beam crossings per second, (equivalent to a bunch to bunch time of 22 microseconds), with at most 1 Hz good event rate. The overall goal of the trigger system is the reduction of the number of accepted and stored events to a rate of a few per second (1-4 Hz).

The following Table shows in detail the number of electronic channels involved in the OPAL detector and the expected data length for a typical hadronic event of 20 charged tracks and 20 photons. About 50,000 analogue outputs require 6 - 15 bit digitisation. The 100 Mhz Flash ADC used for simultaneous sampling of the Central Detector amplitude and time produces 90% of the data.

TABLE 1

Detector	Element	Digitized Electronic channels type	Number	Compacted Data length (Kbytes) Z^0 hadronic event+)	background or Bhabha
Vertex Chamber	600 wires	FADC 6 bits	600	2.4	0.2
Jet Chamber	3840 wires	FADC* 6 bits	7680	128	12.8
Z - Chamber	1296 wires	FADC* 6 bits	2592	6	0.5
Time of Flight	320 PMT	ADC 12 bits	320	0.3	0.1
		TDC 11 bits	320		
E.M. Presampler	16834 strips 2900 wires	ADC 9 bits	19284	0.4	0.1
E.M. Barrel cal.	9440 PMT	ADC 15 bits	9440	0.6	0.1
E.M. End Cap cal.	2200 VPT	ADC 15 bits	2200	0.4	0.1
Hadron Barrel cal.	1152 pads	ADC 12 bits	1152	0.2	0.05
Hadron End Cap cal.	624 pads	ADC 12 bits	624	0.2	0.05
Muon Barrel	230 wires	TDC 8 bits	460	0.02	0.01
Muon End Cap	40000 strips	1 bit	40000	0.02	0.01
Forward Detector	148 VPT	ADC 12 bits	148		
	24 PMT		24	0.2	0.05
	1080 wires	TDC 10 bits	1080		
TOTAL				140	15

PMT : Photomultiplier Tube
VPT : Vacuum photodiode

*) Assumes 20 samples per pulse.
+) Average event has 20 charged tracks and 20 photons.

Assuming suppression of all data items below a given threshold at the beginning of the readout chain the event size is about 140K bytes for a 20 charged track event and 15K bytes for a simple 2 track Bhabha event.

The predicted rate of data recording corresponds to writing one 6250 bpi tape every 30 - 60 minutes. If we further assume that each Z^o event will require 20 sec. of IBM 370/168 CPU time for complete analysis i.e. from raw data to full reconstruction, then we will need approximately 20,000 hours of CPU time per year (roughly 2 - 3 dedicated IBM 370/168s).

In addition, time will be needed for many other software tasks : calibration runs, special trigger processing, program/file management, physics analysis and Monte Carlo calculation. Based on recent experience from UA1, such additional tasks will increase the demand for bulk processing CPU by a factor of approximately 4.

4. BACKGROUND RATES

Synchrotron radiation

A continuing study of the background induced from synchrotron radiation is being made within the ISR/LEP division. The most important source of these photons comes from bending in the set of low beta quadrupoles located at either side of the beam crossing point. Although the quantitative estimates of photon yields are dependent upon the magnetic structure of the machine, and therefore liable to change, the preliminary conclusions are given in LEP Note 439 (P. Roudeau et al.) and LEP Note 441 (K. Potter).

The synchrotron radiation backgrounds can be kept below 10^5 photons per sec incident on the 160 mm diameter beam pipe over a distance of ± 2 m around the interaction point. This represents a background of 2 - 3 photons per bunch crossing incident upon the beam pipe, which is perfectly acceptable for the OPAL central detectors. It should be noted that these estimates relate to a beam current of 3 mA (4.17×10^{11} particles per bunch) and do not explicitly allow for effects from non-Gaussian tails. However, 100% horizontal-vertical coupling has been assumed, and the photon fluxes are particularly sensitive to the value used for the horizontal emittance (doubling the emittance could increase the photon flux by two orders of magnitude).

Off-momentum particles

These are created when the beam particles lose energy through beam-gas bremsstrahlung. Although the particles are almost undeviated from their original trajectory the loss in energy can be sufficient that they fall outside the momentum acceptance of the machine. Such effects have been studied by tracking degraded electrons in order to find the number/bunch swept out by the low beta quadrupoles into the interaction region. The results from A. Smith are given in a series of LEP Notes 164, 186, 445 and 469.

The precise magnetic structure of the machine affects the particle trajectories. The present conclusions indicate that a moveable collimator will be necessary about 120 m from either side of the interaction point. This collimator should be able to approach within 7 beam σ from the inside of the ring and will effectively eliminate all particles of energy greater than 4 GeV produced upstream of the weak bend.

The presence of collimators between the low beta quadrupoles already mentioned as a requirement for shielding against synchrotron radiation, also serves to reduce the off-momentum particle background by an additional factor of 2 in the region ± 3.5 m from the interaction point. The resulting rate of off-momentum particles in this region is now estimated to be 1.6×10^{-3} particles per bunch for each beam, which gives a total integrated rate from both beams of 140/sec.

Although this rate does not appear unreasonable for the OPAL detector, it must be remembered that off-momentum electrons may shower in the beam pipe, and subsequent material of the detector. These can fake high energy events and cause increased spurious trigger rates. Special care will be taken to protect the forward tagging system against this background.

Every attempt should be made to attain the best possible vacuum in the machine, not only to reduce the source of off-momentum particles, but also to minimize the inelastic beam-gas collisions in the interaction region itself.

Other backgrounds

Machine tunnel background : it is expected that, as at PETRA and PEP, the machine will be surrounded by an ambient electromagnetic background. By completely blocking the machine tunnel with shielding at its entrance to the experimental area these low energy electrons and photons can be prevented from approaching the detector. The shield will also serve to inhibit high frequency pick-up.

Low enegy electrons from the RF cavities : these can be removed by the "tunnel shielding", together with, if necessary, a system of weak magnets.

Beam-beam synchrotron radiation : the interaction of one beam in the electromagnetic field of the other, at the crossing point, is estimated to produce ~ 10^{15} photons/sec for 50 GeV electrons. All these photons pass through the interaction region and fall on collimators and distant sections of the vacuum chamber. However a significant $e\gamma$ luminosity is generated (~ 5% of the e^+e^- luminosity), with resulting Compton scattering and pair production

$\gamma e \rightarrow \gamma e$
$\gamma e \rightarrow e^+e^-e$

The rate is ~ 1/2 per bunch crossing with the low energy electrons that are produced normally staying inside the vacuum pipe.

Cosmic ray background : consists mostly of single muons and occasional extensive showers at a rate of 100 Hz over the entire active area of the detector (24 m^2). They are distributed uniformly in time while the bunches cross for a few ns only. A bunch crossing gate provides efficient suppression to the level of < 0.1 Hz. In the first level trigger, cuts in R, ϕ and Z and more stringent timing cuts with Time of Flight counters reduce this background to a negligible level.

Although significant progress has been made in the theoretical understanding of the sources and rates of various backgrounds, these should in general be considered as lower bound estimates. The effects of beam losses from any (unknown) origin will add to the beam-gas bremsstrahlung, and emphasise the need to understand and optimize the design in all aspects of masking and shielding that affect the environment of the OPAL detector.

5. THE TRIGGER SYSTEM

Using the expected LEP luminosity and cross-sections, the rate of real electron-positron events will be < 1 Hz. On the other hand, the expected background rates (off-momentum electrons from beam gas and beam pipe interactions) will be large (~ 140/sec). Since the data acquisition time is a significant fraction of a second, the trigger system must be able to reduce the number of accepted and stored events to the level of, at most, a few per second by removing the background efficiently while accepting all the interesting events.

Physics Considerations

The trigger system should efficiently accept events originating from e^+e^- annihilation into its many interesting final states such as hadronic jets, charged lepton pairs and radiative production of the Z^o decaying into neutrinos. Moreover, one would like to trigger with reasonable efficiency on two photon processes where a low multiplicity of charged tracks and/or photons is produced. Also, because the OPAL chambers are sensitive to tracks of less than minimum ionization, we will be able to search for, and trigger on, exclusively produced free quarks.

Multihadron final states provide a relatively simple trigger from their deposited electromagnetic or hadronic energy and their high charged multiplicities. However the low multiplicity events, including two photon processes and neutrino counting experiments, will demand more sophisticated techniques. Such processes may need vetoes from various detector components to suppress the otherwise excessive rate from background events.

The ability to select exotic events (like heavy neutral leptons) will require an inclusive particle trigger coming from triggers that include electron, muon, photon or quark candidates.

To achieve highly efficient and quantitatively understood triggers it is necessary to incorporate a degree of redundancy using different detector elements and characteristics to identify a given class of events.

As well as satisfying these requirements the initial trigger must occur within the 22 μsec interval between bunch crossings to minimize dead time effects. The system must therefore be both intelligent and fast. These requirements can only be met by a multi-level system where fast early triggers reduce most of the unwanted backgrounds and a later, more sophisticated, trigger filters the remaining limited data. The OPAL detector has a variety of triggering capabilities as described below.

System Overview

The trigger system acts in two stages. The first stage occurs in the 22 μsec between bunch crossings. The second stage occurs between the initial acceptance of an event and the transfer of the data to the recording medium. The flow diagram of these levels is shown in Fig. 1. Data digitisation is initiated by the beam crossing signal and all the elements of the detector have their data available within 10 μsec. These data can be used to abort within $\leq$ 18 μsec from the beam crossing signal any trigger that does not meet the tests for a good event. Digital information from the detector is then passed to the second level where fast microprocessors will be used to further filter and also to tag the data before passing it to the main computer. This processing will reduce the data rate to $\leq$ 4 Hz, corresponding to $<$ 5% dead time.

The trigger elements at level 1

In Fig. 2, the time axis is related to the response times of the various elements which are shown as dotted extensions to the boxes representing each element. It is important for the design of the trigger to note that every element of the detector has its signals available for the trigger system within 10 μsec, leaving 12 μsec before the next beam crossing to make logical decisions on this information and to reset the electronics.

The elements at the top of Fig. 2 are logically grouped together on the basis of the speed at which they produce their output and the fact that the data can be grouped into $\theta\phi$ matrices. The first four give also the energy of the particles and can easily be summed to give total energy analogue signals. They can also be used to count the number of particles which have fired them.

Topological information from the electromagnetic calorimeter is achieved by dividing the lead glass blocks into contiguous groups and assigning each group an address in a $\theta\phi$ matrix. Hits are then recorded as entries in this matrix. The towers of the hadron calorimeter and the TOF counters are also given addressing systems in $\theta\phi$ appropriate to their structures.

The energy and topological information and multiplicity of an event are produced in a few μsec. They are then passed to a trigger matrix box for further processing in combination with information from the other elements of the detector.

The next group of devices are the tracking chambers (vertex, jet and Z-chambers) which are to produce $r\phi$ and rz track reconstruction and the number of tracks. The vertex detector data are available in ≤ 2 μ sec while the others take ≤ 8 μ sec. This information is tested in $r\phi$ and rz (momentum, origin, and number of tracks). It will also be possible to combine the $r\phi$ and rz information and produce $r\phi z$ track candidates. This masking of data and retrace operation will take place in the unit labelled $r\phi$ and rz track finder in Fig. 2. The data from it will be passed to the trigger matrix box where they will be used to make the level 1 decision. The jet chamber will also provide a quark trigger by looking at the ionization of the track.

The muon chambers will give the number of particles which get through the hadron calorimeter together with their track coordinates. The barrel chambers have long drift times and will be the last elements to be logged (≤ 10 μsec) while the end cap chambers will be logged in ≤ 2 μsec. These data will be processed for number of hits, put into $\theta\phi$ matrices, and passed to the trigger matrix box.

The forward detector will select Bhabha events and single/double tagging triggers for 2γ events. These triggers will also be fed to the trigger matrix box.

The trigger matrix box will, after receipt of the information from each element, combine the data and make decisions on the topology and energy of each event. For example, it will correlate the $\Theta\phi$ matrices with the track coordinates and check the number of tracks or clusters. Thus various physics processes can be selected by these filters. For example, neutral hadrons and photons can be selected by the energy trigger, dileptons by the topological trigger and jets by combinations of the two. The quark trigger may also be implemented and combined with the topological trigger.

The trigger matrix box will decide whether to reject a given event, or to accept it and pass it on to the second level for further decision making. Digitisation electronics will be started by the beam crossing signal and automatically reset unless the event is accepted. In this case, the trigger box will send a signal to start the process whereby the digitised data are transfered to the buffer memories. If the event is rejected, about 4 µsec are needed to reset the electronics - thus leaving 18 µsec to make the trigger decision.

The trigger matrix box will be computer controlled and its status for each run and/or event recorded on the data tape. This is necessary to keep track of the status of the parameters.

The trigger at level 2

The level 2 trigger is not yet designed. It is foreseen that higher level processors, performing on-line calculations, will reduced further the background events. Some class of events, however, will not need testing at this level and can be passed-on immediately. The processors could be specialized fast track processors (like in the TASSO experiment) and emulators. Possible places for connecting such processors to the data acquisition system are the master crate (see chapter 6) and the main VAX computers. Given the readout speed provided by the front-end data acquisition system, about 10 msec per event are available to the second level trigger without imposing additional dead-time.

Summary

Only a preliminary trigger scheme has been described in this document. It is, however, based on the experience in the group in general and on the JADE detector in particular. The plan uses simple fast triggers that are available within 18 μsec, e.g. number of hits and energy deposition, etc. Thus in the beam-beam crossing period complex decisions can be made, for example, on $r\phi$ and rz pattern recognition. These fast triggers will eliminate the dead time associated with waiting beyond the next beam crossing to filter the background. Finally, complex hardware sieves involving microprocessors or hard-wired array logic can be used to reduce the dead time associated with reading spurious events, to the $\leq 5\%$ level. The fast and varied data from OPAL can be used for efficient triggering not only on standard processes but also to search for rare and exotic processes such as heavy leptons and quark production.

6. FRONT END DATA ACQUISITION

The primary functions of the front end data acquisition system are triggering, signal processing, digitisation, data acquisition with a minimum dead time, data compaction (e.g. zero suppression), filtering (event selection) and the sending of data to the mini-computer.

The OPAL detector systems, and their corresponding diagnostic hardware and software will be developed independently by several groups. As the detector is being assembled, the data acquisition system must be capable of accommodating several concurrent users, each working on a different subsystem. A tree structure with autonomous sub-systems is proposed for this purpose. This allows a maximum parallelism with distributed intelligence, local data buffering and data reduction at each readout level.

The scheme under development is organised around a powerful system of MOTOROLA 68K microprocessors in VME crates placed between the detector front end electronics and the 32 bit minicomputer system (see Fig. 3).

Dead time is minimized by sending the trigger interrupt directly to any level (front-end crate, sub-system crate, master crate) and then accepting another event before the previous event has reached the top of the readout chain.

Each subsystem has a calibration procedure which must be controlled by the data acquisition system, the calibration results being entered into the system data base. Automatic methods of monitoring the operation of all major subsystems are needed. Access to the data at all levels of the system must be provided for monitoring. Dedicated mini or micro computer systems which spy on the data flow at each branch are envisaged to perform this function.

Front End Crate Level

The proposed system is open to the use of CAMAC, FASTBUS or VME crates for the front-end electronics. The most important operation at front-end crate level is zero suppression, to keep the data to manageable proportions. Use of hardware processors (Scanner) for this simple operation will be necessary for most of the sub-detectors. Wherever it appears necessary, for dead time minimisation, to push the parallel working up to the front-end crate level, auxiliary crate controllers (CAC) are used to collect the data simultaneously in each crate. The auxiliary crate controllers may be used to subtract pedestals or fit parameters to the raw data.

A system containing intelligent auxiliary crate controllers and hardware processors will be used for the data acquisition of the full size prototype of the central detector during 1984. As this system produces very big events (80 kbytes before zero suppression) experience in data compaction, data buffering and also histogramming of raw data at crate level will be gained in a realistic environment.

Sub-system Crate Level

The front-end electronics crates are organised in sub-systems (see Fig. 3) which are driven by CBAs (Controleur de Branche Auxiliare) with buffer memory and processing power. This is necessary to accommodate the very large number of crates, and also to have the maximum parallelism to minimise the data transfer time. Several CBA are put into a Sub-System crate to control a part of the detector.

All sub-system crates will be connected together, and to the VME master crate, with an appropriate link.

The processing power of the CBA may be used to make more elaborate software checks than is possible at crate level, having at hand the content of the whole branch controlled by that CBA.

Test Computer - SPY access to data

It is very important for testing and debugging purposes to have the possibility to spy on data at the branch level. Such spying is done by a Test Minicomputer, used for setting-up, debugging, monitoring (and possibly calibration) of each part of the detector independently of the main acquisition computer. This independence of the branches in a test configuration is regarded as essential for the commissioning of a detector of this size. Local detector histograms may be built for monitoring purposes, thereby saving computing resources in the main acquisition computers.

It is considered most appropriate to spy on data in the sub-system crates, where the CBAs contain the compacted detector data.

Master Crate Level

Having the data from the entire detector available and being placed at the entrance to the main data acquisition computer, the master crate is the central part of the front-end readout system. It plays the role of a buffer for many complete events, and presents the events, whenever one is available, on the request of the main computer. The master crate is a VME crate which is driven by a CPU module that we call the M68000 master. It contains buffer memory and the DMA connection to the main computer.

With this scheme, the complete acquisition will be performed by a larger number of modules (CAC, CBA, MASTER). Each module will contain : a 68K processor, a block of 256 kbytes of dual port memory, a local Interface to the corresponding branch (CAMAC, VME, FASTBUS), and Input - Output connections for triggering purposes. Two serial ports are available for network connection, program loading and local histogram display. One of these ports, connected through a Local Area Network, will be used for control and diagnostic purposes.

Current status

As of January 1984, the following modules have been built and used for beam tests of OPAL sub-detectors :

a) The CAC, the CAMAC auxiliary crate controller with M68000 CPU, 256 kbytes of RAM and 192 kbytes of EPROM.

b) A VME-CAMAC branch driver.

c) A VME module able to drive a single FASTBUS crate segment.

The following modules are in an advanced state of development and will be ready in spring 1984 :

d) The CBA, the auxiliary branch controller with a M68000 CPU.

e) The module allowing a multi-crate extension in VME (announced by the LEP/SPS division).

Finally, the design of the following modules will be undertaken in 1984 :

f) The extension board of the CAC allowing it to work in DMA mode.

g) The DMA interface from the M68000 MASTER to the VAX mini-computer.

h) The VME module able to drive FASTBUS modules on a cable segment.

i) General purpose VME modules.

Microprocessor software

Software for data acquisition in the microprocessor system will be provided by the SACLAY team using a VAX provided by SACLAY.

We intend to use on each microprocessor of the OPAL experiment a multi-task monitor. We are considering using the RMS68K monitor which has been adopted by CERN as the standard real-time kernel for the M68000.

The microprocessors handle the following tasks :

i) data acquisition, in response to the trigger interrupt.

ii) filling of the histograms.

iii) monitoring.

iv) handling of the messages from or to the local area network.

As these tasks are different, have different priority and are to be done at different times, and as they have to share data, not using a multi-task monitor would mean in fact rewriting and incorporating inside the program the facilities normally offered by a multi-task real-time monitor. This means a much heavier program, much more error-prone and much more difficult to debug.

7. DATA COLLECTION AND REMOTE RECORDING

Central Data Acquisition will be performed initially by two VAX 11/780 computers, provided by NRC (Canada) and the UK, and a VAX 11/750 purchased jointly by OPAL Institutes. These machines have been selected in view of previous experience and widespread use within the collaboration.

Event data will be transferred to the VAX computers via a fast DMA channel from the VME Master crate. Events are buffered by the microprocessors, and the data transfer is therefore desynchronised from the event trigger. At this point, the data are passed through sophisticated on-line filters, and are then made available for general on-line monitoring. OPAL will enhance the VAX capabilities for on-line filtering and data reduction by using Emulators.

It is possible by further analysis to identify events as Bhabha, Cosmic, Hadronic, etc.. This is particularly useful as it allows rejection of events and on-line calculation of cross-sections, and is also of value in the off-line analysis. If enough emulator power is available, it may be possible to attempt a full reconstruction of particular event samples using the off-line analysis code. Even though calibration constants are not precisely known at this stage, a rapid feedback of reconstructed data to the monitoring routines will prove extremely valuable. An event display is of particular value when used in association with this classification, for example as an aid in trigger studies.

Thus it is possible, before recording data on a storage medium, not only to filter the events - but to classify them using algorithms that require significant event reconstruction. Rare event types, for example - heavy leptons, quark candidates, ... can be flagged and, if needed, also sent to a special output stream for fast off-line processing.

Software for this system will be drawn as far as possible from existing common on-line software packages. OPAL has started to use the CERN VAX Data Acquisition system in a test beam. This software will be modified to manipulate the large events and high data rate from the OPAL Detector prototypes, and to incorporate the necessary dialogue with the front-end microprocessor system. While the tests are underway, measurements will be made on the running acquisition system to determinate which portions will be suitable for adoption into the final OPAL acquisition system.

It is anticipated that very considerable development will be required, even if the majority of the present CERN VAX data acquisition system can be used. Areas of new software include remote data recording, use of multi-Vax systems, control of the front-end system, microprocessor histogram information retrieval, and many others.

Code for on-line filtering will be developed in conjunction with the more sophisticated off-line version. Often these are developed separately since the on-line version typically trades track finding efficiency for high computing speed whereas the off-line version attempts to achieve the highest track finding efficiency possible. The OPAL versions will be kept as close as possible.

The collaboration intends to record data at the CERN Computer Centre and requests full CERN support for this. This will not only relieve the burden of tape handling in the experiment counting room, but will also allow immediate use of more sophisticated storage devices as they become generally available. Provision is being made to record data locally at the experiment on 6250 bpi tapes, for those occasions when the link is not operational.

In addition to on-line checks, part of the data will be passed through a validation process at the Computer Centre. This will immediately pin-point any errors in the format and contents of the event records.

8. ON-LINE MONITORING

The purpose of event checking and monitoring is to discover, as early as possible, faults and abnormal behaviour of the detector. Monitoring activities will be performed where possible in the processors of the front-end data acquisition tree. For example, histograms such as hit maps may be filled in several parts by processors close to the detector. Data from such histograms would be tranfered via a Local Area Network (LAN) for display and archiving.

Monitoring software requiring information from more than one sub-system of the hardware acquisition tree would be executed in the central data acquisition computers or attached emulators. Higher level software of this class would be likely to require storage or processing resources exceeding those available in the front-end acquisition tree. For successful operation of such a system, the operator should not need to know where individual histograms are actually stored. In order to reduce the operator load as far as possible, and more particularly in view of the size and complexity of the experiment, an automatic histogram checking facility will be employed. Such a system is currently in use in some PETRA experiments, particularily JADE, and has been shown to be a considerable asset.

Detector graphics displays will play an important role in the monitoring phase of the on-line system. If at all possible, we will keep standard graphics packages for the entire OPAL operation, including Monte Carlo, on-line, interactive debugging and routine off-line processing.

A more detector-dependent type of monitoring is required for use by hardware experts in the final diagnosis of fault conditions detected by the main monitoring software. Where necessary, this would be implemented in dedicated computers operating in 'spy' mode on the detector readout. Such computers, probably previously used in test systems, would be largely independent of the central data acquisition system, and diagnostics could therefore benefit from the extra detail available in the data prior to full processing in the acquisition tree.

9. OPERATOR INTERFACE

The operator interface to the data acquisition system is of special significance since it is by this facility that the success (or otherwise) of the system will be assessed. A good interface will also greatly add to the efficiency of the operating team and thus minimise the effort consumed in routine day-to-day running of the apparatus.

Common operator activities include experiment control (establishing detector operating conditions), data acquisition control (run and tape manipulation), and detector checking (e.g. viewing histograms). The Operator Interface to these activities has in the past often been of the same type throughout - either command or menu driven, and relatively little attention has been paid to possible on-line applications for modern interactive input devices. We consider that implementation of these more flexible media may lead to a significant improvement in the operator environment, and that their use should therefore be investigated.

10. DIALOGUE WITH THE LEP MACHINE

Three types of signal/information are foreseen in the dialogue with the machine.

Signals related with safety

It has been proposed to equip the LEP experimental Areas with a safety surveillance system, GSS (LEP-IES/KP/CC), which will be connected to the various components of the experimental setup and to the LEP Main Control room. The main purpose of the GSS is clearly related with safety, but it is also designed to exchange information between the machine and experiment (see below).

Signals/information provided by the machine

- Prepulse : a pulse with a fixed time relation to the time of the actual bunch crossing (~ 500 - 1000 ns before bunch crossing), to start ADC's, TDC's etc. This signal can be derived from the high frequency system.

- Precise bunch crossing signal : to obtain a bunch crossing signal, the experiment needs access to the signals from two pick-up stations located a few meters to each side of the interaction region. The processing of these signals will be done by the experiment.

- Information related with the status of the storage ring :
  - beam energy (MeV)
  - positron beam current
  - electron beam current
  - frequency
  - time after refill
  - lifetime positron beam
  - lifetime electron beam
  - vacuum in the IR

This information will be used by the Data acquisition system and should be updated every $\leq$ 30 sec.

Signals/information provided by the experiment

- High Voltage status signal as interlock to veto injection
- status/value of the solenoid magnetic field
- counting rates from the luminosity monitors including accidentals rates
- a few signals showing the background conditions in the experiment : (e.g. Central Detector integrated current, FWD singles rate..). These signals are vital for optimisation of the running conditions.

11. PHYSICAL LOCATION OF ON-LINE COMPUTER EQUIPMENT AND EXPERIMENT CONTROLS

Figure 4 shows an artist's impression of the complete OPAL detector in the garage position underground. The front-end electronics will be distributed around the detector in mobile huts suspended near the side walls (Gondolas) and in huts attached to the side of each of the two large yoke modules (Rucksacks).

Figure 5 indicates a possible matching of each sub-detector with an appropriate Gondola or Rucksack. The Master Crate and the fast trigger matrix box will be located in Rucksack TR. Space at the end of the underground area is available as a local control room and for the local test computers.

As much as possible of the computer equipment will be located at ground level. This is desirable both for ease of maintenance, and from the point of safety, to minimise the number of personnel underground. It is intended to house on the surface the VAX data acquisition computers and associated peripherals, together with the majority of terminals and LAN controls.

During the experiment commissioning, space underground will be needed for dedicated minicomputers, the microprocessor support computer and their terminals. When stable running conditions have been achieved, most minicomputer terminals will be moved to the surface.

Space at ground level for the on-line computers will be required at the earliest possible date. The current plan for I6 does not make the computer building available until t_o+54 months. This will not allow the full power of the acquisition system to be available to physicists and engineers during detector commissioning. Serious re-evaluation of the plan is called for.

We anticipate that early installation of the LAN will be a considerable asset. This will provide the necessary flexibility to enable test computers and terminals to be moved as required by the changing status of the detector hardware.

12. GENERAL CONVENTIONS AND PROGRAMMING STANDARDS

The OPAL off-line group has recognized that for successful and rapid production of physics results from such a complex detector it will be necessary to define general programming standards and conventions. These standards include overall system design, language, data structure and dynamic memory management, coding procedures, source maintenance and transport, and data formats.

i) Overall System design

This is fundamental and an important prerequisite to any successful system. Great care and attention to detail will be exercised during this design phase to produce a system which will be easy to use, easy to maintain, easy to understand and easy to transport. Detailed specifications will be written, distributed, discussed, modified and, finally, agreed upon. Documentation will be a very important part of OPAL software and will be embedded in the code from the beginning. Existing routines and packages will be employed whenever possible, especially those library routines and algorithms of the CERN Program Library which have been widely tested and are available on many different machines. Modular methods - using sets of routines which handle different detector components independently - will permit flexibility, e.g. partial processing of data.

ii) Language

Since it is apparent that FORTRAN will remain the principal language of High Energy Physics throughout this decade at least, OPAL software will be coded in FORTRAN 77. Machine dependent code will be avoided whenever possible.

iii) Data structures and dynamic memory management

Extensive experience has already been accumulated with the ZBOOK system, particularly with the Monte Carlo simulation of detector response using GEANT. ZBOOK will probably be adopted as the data structure and dynamic memory manager for OPAL software.

iv) Code Procedure

The OPAL off-line group will define specific coding conventions, plan COMMON blocks, suggest a scheme of mnemonics, organize the concise commenting of routines and define data card standards (e.g. FFREAD). Most programs will include a comprehensive run summary.

v) Source maintenance and transport

In the absence of any suitable alternative, the machine independent program PATCHY will be employed for the basic book-keeping and management of the source code. Transport from machine to machine will be effected either via the X-25 public networks or via tape with the source PAMs in CETA format. We would hope that CERN would accelerate their developement of a replacement for or an improvement to PATCHY.

vi) Tape Format

EPIO permits an internally identical format for all tapes within the analysis chain from the raw data, compressed data, reconstructed events, simulated Monte Carlo events, through to final physics data summary tapes. EPIO avoids the headaches of tape format incompatibilities between different computers and enables partially processed data to be restarted at different stages in the analysis chain.

13. THE OPAL MONTE CARLO

Monte Carlo simulation of the OPAL detector response to several physics processes has already been carried out using the general program GEANT and the package of OPAL interface routines GOPAL. This experience has enabled numerous improvements to be made to the GEANT package, in particular, the method of detector geometry description, the tracking mechanism, the treatment of particle decays and the generation of secondary interactions. In addition, a sophisticated drawing package enables detailed views (see Fig. 6) of the OPAL detector with or without tracks superimposed.

The Monte Carlo is now heavily used by a number of groups to optimize their detector designs. Many USER-routines have been coded which will be improved/modified once the final design of OPAL is frozen. The complete package will :

i) permit a detailed simulation of the detector response, including the hadron calorimeter (a LEPC milestone),

ii) Have, as options, a variety of event generators (including radiative corrections)
e.g. LUND → hadrons, $e^+e^- \rightarrow e^+e^-$ ($\mu^+\mu^-$, $\tau^+\tau^-$, $\gamma\gamma$), 2-photon events, beam-gas backgrounds, rare processes (e.g. $e^+e^- \rightarrow Z^oH^o$, $e^+e^- \rightarrow W^+W^-$).

iii) permit the development and testing of trigger algorithms,

iv) permit the development and testing of on-line filtering algorithms,

v) permit the development and testing of pattern recognition routines, track fitting procedures and event vertex calculations,

vi) permit the simulation of raw data at any stage in the on-line data acquisition process, essentially for testing the reliability and effectiveness of the on-line intelligent interface (the ability to do this will be built into the system from the start),

vii) permit detailed display of the apparatus with magnification/rotation option under user control, and

viii) permit the development and testing of calibration procedures.

Current experience indicates that the CPU time needed for full detector simulation is considerable, and will almost certainly grow as the system becomes more sophisticated. Optimization of this code will be a major challenge. To avoid saturation of computer resources, the opportunity of running the Monte Carlo on banks of suitable mainframe emulators is an attractive possibility.

14. NETWORKING ASPECTS

It has become clear in the last 12 months that networks will play an enormously important role in the LEP experiments. The need for networks arises from :

a) Size : A large number of processors are required to analyse and control the data, and these must communicate with each other and with the experimental team.

b) Location : Full access from the experiment to CERN computer facilities must be preserved, even though the site of the experiment is remote from CERN.

c) Internationality : For experimental teams in many countries, the level of access to the remote experiment will determine to what degree they can contribute.

We therefore identify four main areas of network which will be required by OPAL (as depicted in Fig. 7).

Local Area Networks

OPAL will employ many microprocessors, several minicomputers, and at least three VAX computer systems for data acquisition and control. The various computers must be able to communicate freely to ensure a proper flow of control and to enable automatic testing and fault diagnosis.

Users at terminals situated in many different areas of the experiment will require access to a range of information, often coming from more than one processor.

We believe that recent developments in local area network (LAN) technology make feasible the type of dialogue required, and although there is little experience in the use of a LAN to connect many processors, we propose to use this method to achieve the required functionality.

An important by-product of this philosophy is the ease with which computers and terminals may be moved relative to one another. Thus the LAN may play an important role while the detector is being installed (a time at which the optimum location of computer equipment is very difficult to predict), provided that it is working reliably at an early date.

CERN-wide Networks

The OPAL experiment will require access to many facilities on the main CERN site, and will hope to use an upgraded CERN-wide network to do this. Among the services required are :

- Access to the LEP control system, for exchange of parameters such as machine operating conditions and beam quality;
- Facilities for storage of large files, and for bulk printing;
- Use of editors and utilities on the central computer system;
- The possibility to submit Batch jobs, manipulate job queues, and retrieve job output (both ASCII files and Graphics).

It is expected that members of the OPAL team will also work on the main CERN site. For these personnel, proper provision will be required to ensure easy access to OPAL private facilities at the experiment.

Fast Data Links

In all the LEP experiments, data will be generated underground and will be transported over a fast link to computers located at ground level. We consider that this procedure would benefit from using technology similar to that used in other fast networks, even though it is not strictly a network problem.

OPAL proposes to record data at the CERN computer center on a high-density recording medium. It seems likely that the future network facilities at CERN will be unable to sustain the required OPAL data rates (aggregate throughput ~ 1 Mbit/sec), and thus a dedicated "point-to point" link may be required.

Wide-area and International Networks.

Experiments at LEP involve participation by physicists, programmers and engineers from a large number of countries. Many of these will be based in home institutes for some part of the lifetime of the experiment.

Rapid installation and optimum running of the experiment will therefore depend to a greater degree than ever before on the availability and reliability of full access to the facilities in the experiment counting room from outside CERN. We attach the greatest importance to the provision and support of full remote network access to CERN and an expansion of the current X25 facility at the earliest possible date.

Even before LEP starts operation, sufficient bandwidth will be required for reasonable access to On-line displays from outside CERN.

General Network Considerations

General use of networks may pose a security problem, in that simple microprocessor systems on a LAN are not in general equipped to reject malicious network access. Nevertheless, the need for security must not make access to the experiment for real users impossibly difficult. This point is a major consideration because of the complex network routing from outside CERN to a particular processor at the experiment.

There is an urgent need for internationally accepted network protocols which support terminal, job manipulation, file transmission and inter-program traffic between computers from different manufacturers and in different countries. Such protocols are desperately needed both on and off the CERN site. We urge CERN to pursue, with the greatest energy, efforts to improve products in this area.

15. TOOLS OF THE TRADE

The LEP Computing Planning groups WG1, WG2 and WG3 have made specific recommendations for both upgraded and new facilities for the LEP era. CERN should give high priority to the following items which we believe will be of crucial importance to an early success of the OPAL off-line software:

i) Software tools

Most of the OPAL software development will be made outside CERN, in particular in the first years. Several laboratories use IBM, or IBM-compatible, machines whereas other institutes use either VAX computers or other machines of similar type. The collaboration recommends full CERN support for the VM operating system on IBM and VMS on VAX. We encourage CERN to adopt interactive systems to facilitate the management of big source files (an extension of / replacement for PATCHY), document preparation, data presentation, etc..

ii) Emulators

Recent experience with main-frame emulators (168/E, 370/E) shows considerable promise for cheap and reliable bulk computing in both on-line and off-line applications. With the projected CPU loads of LEP experiments, together with the similar demands of Monte Carlo calculations, easy access to banks of emulators would ease considerably the load on the central computers.

OPAL is already gaining experience in this field. The Israel groups have delivered and made operational a 370/E at CERN for Monte Carlo studies. Running the OPAL Monte Carlo, the 370/E had a performance equivalent to 1/4 IBM 3081/K. Bonn has taken delivery of a 370/E and this should be operational shortly. Both emulators will be coupled to VAX 11/780s via Ethernet.

iii) Data base system

Many large experiments have endured painful experiences in the handling of diverse constant files, particularly those associated with time-dependent calibration. This headache will be removed when a reliable Data Base System is provided for the management of LEP machine data, run-logging, tape information, calibration files and general book-keeping data.

iv) Graphics facility

PETRA experience with solenoid detectors, in particular JADE, has shown there is heavy use of high quality interactive graphics facilities to correct pattern recognition errors, to resolve ambiguities of coordinate assignment and generally to improve the analysis code. It has also been used to sort out complex event topologies and for event validation. An easy-to-use, multi-user, interactive system will be essential at LEP where the event multiplicities are considerably higher. This will need a big software effort both by CERN and OPAL. The advantages of an early Monte Carlo simulation program will be to help develop the necessary graphics software packages prior to LEP turn-on.

v) Personal Work Stations (PWS)

The RAL VAX is now fully available at CERN for both on-line and off-line software development, for Monte Carlo running, and for the analysis of test beam data. It is now the main computer for our software development. It is expected that this VAX will be rapidly saturated by users who require a lot of system resources. We thus envisage to build a local area Network of Personal Work Stations each with at least the power of the Apollo DN320. The number of workstations will increase with the number of OPAL physicists at CERN. Priority will be given at the beginning to the tasks requiring interaction and graphics. OPAL supports strongly the CERN personal workstation project. In particular we would like to encourage the development of modern user interfaces, documentation systems mixing text and graphics with output on a laser printer. The development of a 3-D event scanning system is considered to be essential, in particular, if graphics engines able to perform real time dynamic graphics can be attached to these stations.

The LAN should have good connections to the OPAL VAXs, the OPAL main-frame as well as to CERNET and the X25 gateway. We think that such a network should be composed of many different devices (which are all software compatible) for documentation purposes (including graphics), event scanning and program development and testing. It is expected that CERN will contribute substantially to the hardware and software support needed for the installation and developement of PWS.

vi) Error detection

One of the most important, yet often forgotten, tasks in a complex analysis system is that of error detection, diagnostics and correction. Field testing of software products by different people on different machines running different operating systems will be encouraged from the very beginning. Monte Carlo simulation events will be needed to input data into the many stages of the trigger/filter/data acquisition system and to test the integrity of the intelligent branches. The procedure will also help to isolate detector component failure. This is typically an extremely unrewarding labour yet, nevertheless, essential.

vii) Resource Management

With upwards of a hundred possible OPAL users of the main central computer it will be necessary to develop "spy" programs to ensure that the allocated resources are being properly used. In many cases, even with the best will in the world, some fraction of users will misinterpret instructions and saturate a particular resource. Such "spy" summary data will enable a somewhat smoother data flow and augment the speed of analysis results.

16. CONTACT WITH OTHER LEP GROUPS AND CERN

With four large collaborations preparing separate experiments for LEP a considerable effort of software development will take place. This effort, measured in hundreds of man-years, can be more effectively used if close contact between the groups is maintained. It has been proposed that meetings take place to discuss common problems, to exchange expertise and, more importantly, to agree on common proposals for specific arrangements and implementation of new tools and general packages. Obvious examples where this could be beneficial include remote data recording, software tools, event generators, microprocessor support, LAN support, data acquisition support, etc.. OPAL will pursue these possibilities vigorously.

17. ESTABLISHMENT OF AN OPAL SOFTWARE GROUP AT CERN

OPAL will establish a nucleus of software effort at CERN which will grow steadily during the years prior to LEP turn-on. This group will be composed of CERN staff and members of the OPAL collaboration who will come to CERN for extended periods. This central group will actively coordinate the effort of the various members of the collaboration, will engage in frequent discussions with their counterparts in the other LEP experiments and will interface with CERN to ensure that needed facilities are provided.

On a more mundane level, the central group will, on receipt of new modules and/or documentation, quickly check their validity before disseminating them to the collaboration. They will create versions of modules for the different machines in the collaboration. Further, they will be responsible for checking that new software changes are compatible with work done elsewhere and for integrating these changes into current master packages. The CERN group will also ensure that all documentation is distributed as soon as it has been checked and that modules are distributed as soon as versions for the various machines are available. Finally, the group will be responsible for cleaning up the master packages and for optimizing them as seems appropriate and as time is available.

18. TIMETABLE FOR HARDWARE AND SOFTWARE DEVELOPMENT

	83	84	85	86	87	88	89	90
Prototype CAMAC Intelligent Branch CBA, CAC	----	----						
Final Design of CBA in VME	----	----						
Fabricate all intelligent modules		--	----	---				
Test DMA				----				
Test each branch				----	----	----		
VAX software for microprocessors	--	----	----	----	----	----		
Use VAX DAQ system in test beam		----	----	→				
Design on-line software		--	--					
Write on-line software			--	----	--			
Test full system					----			
I6 Computers installation, final tests						----		
First Beam crossing. Real data							----	---→
RAL VAX 11/780 at CERN	----	----	----	----	----	----	----	----
OPAL VAX 11/750 in test beam		----	----	→				
CANADA VAX 11/780 at CERN					----	----	----	----
TOKYO mainframe at CERN						----	----	----
Establish software group at CERN	--	----	----	→				
Write detailed Monte Carlo	--	----	----	→				
Write specifications of OFF-LINE code		--	----					
Write OFF-LINE code & graphics				----	----	----	→	
Prepare fake data & analyse						----		
Analyse real data							----	---→

19. CPU POWER REQUIREMENTS AND AVAILABILITY

With LEP running at full luminosity at the Z^o peak we will need the equivalent of between 10 and 12 IBM 370/168 fully to process the data (including the CPU time needed for physics analysis and Monte Carlo). Before this period we will nevertheless require considerable computing resources. Between 1983 and LEP turn-on there will be a definite and gradually increasing demand for CPU power for program development and Monte Carlo analysis of detector performance. Most groups within the collaboration have good access to local mini-computers and remote main-frames on which much of the development work will be based. Some institutes are acquiring emulators to enhance their capability, for example both Bonn and Weizmann with 370E's.

The following table summarises the current computing resources within the OPAL collaboration together with the actual number of hours of machine availability under the assumption that all OPAL personnel were working full-time on OPAL now.

LOCATION	CURRENT MACHINES (No. HOURS/YEAR)
Birmingham	IBM 4341 (2000), 370/E
Bologna	VAX 11/780 (1200)
Bonn	VAX 11/780 (1000), IBM 3081/D (700), 370/E (7000)
Cambridge	VAX 11/780 (4700)
Carleton	see NRC, Canada
CERN	VAX 11/750 (7000), VAX 11/780 (7000), 370/E (7000)
Chicago	HARRIS 125 (7000)
Freiburg	UNIVAC 1182 (5000)
Heidelberg	IBM 4341 (600), IBM 3081/D (400)
Manchester	GEC 4090 (3000)
Maryland	IBM 370/168 (150), UNIVAC 1182 (250)
NRC Canada	VAX 11/780 (7000), IBM 3081/D (1500)
RAL	ATLAS/10, IBM 3081/D (600)
Saclay	VAX 11/750 (3500), IBM 3081/K (300)
Technion	see Weizmann
Tel Aviv	see Weizmann
Tokyo	FACOM M190 (7000)
UC London	GEC 4085 (3500)
Weizmann	IBM 3081/D (1000), CDC 170/855 (500), 370/E (3500)
QMC London	VAX 11/750 (5000)

Although large main-frames exist at several institutions, it will take considerable effort and carful management to install a parallel data reduction system at these remote laboratories. Under stable analysis conditions, say 1 - 2 years after LEP start-up, these main-frames would contribute roughly 30,000 hours (IBM 370/168).

At CERN we envisage a steady growth in the number of OPAL personnel requiring access to the facilities of the Computer Centre. The RAL VAX 11/780, currently located in the Computer Centre, the OPAL VAX 11/750 in the test beam, and the Canadian VAX 11/780 (to arrive in 1986) will satisfy only some of these requirements. We have also established a 370/E (provided by Weizmann) at CERN to permit a better turnround for long Monte Carlo jobs. The following Table shows an estimate of the number of OPAL active users of the Computer Centre and the number of CPU hours (IBM 370/168 equivalents) required over the period 1983 - 1990.

Year	No USERS	No. CPU hours required from CERN
1983	4	100
1984	8	500
1985	12	2000
1986	16	4000
1987	16	8000
1988	32	16000
1989	64	30000
1990	64	40000

Several clarifications are in order :

i) The small number of CPU hours in the period before 1988 assumes that CERN will provide a bank of main-frame emulators for long jobs and that Personal Work Stations will be available for much of the code development.

ii) The Tokyo group are negotiating for the acquisition and delivery to CERN in 1987/1988 of a large main-frame computer. This will be our major analysis computer after its installation.

iii) For the first two years of LEP operation, when most of the OPAL team will be on-site, we wish to satisfy the bulk of the computing needs of OPAL at CERN. Although we do not expect to be recording data at full rate during this period, a sizeable fraction of the 10 - 12 IBM 370/168 equivalents will still be needed.

20. COSTS

Trigger System Costs

Fundings for the trigger system will be provided as follows by the three groups

Group	Funds MSF
SACLAY (trigger matrix, fast logic)	0.3
TOKYO (EM trigger)	0.3
UK (track trigger)	0.15
TOTAL	0.75

Computer equipment costs

The price of commercially available computer equipment and electronic components is changing rapidly. It is therefore possible to provide only estimates of the funding resources required to equip OPAL with adequate data handling equipment capacity. Furthermore, new techniques for data processing, communication, and control are expected significantly to change the data handling philosophy in ways which cannot be predicted.

Central Data Acquisition will be performed initially by three VAX computers. We propose to up-grade the present configuration of these computers to a level appropriate to the requirements of the OPAL Data Acquisition System. Large amounts of disc storage will clearly be required to support the very large file base necessary for an experiment of such complexity. Although data will be recorded at the CERN Computer Centre, sufficient tape writing capability will be needed locally to cope with high data transfer rates expected at LEP in the event of link failure. The attached emulators will place further demands on the system both in terms of disc storage and number of tape units. The equipment to be provided is as follows :

Institute	Items	cost (KSf)
From CEN Saclay		
	Crates - VME - CAMAC (20)	100
	CPU 68000 processor cards (64)	200
	RAM memory (64x256 Kbytes = 16 Mbytes)	140
	link to computer (DMA)	100
	General purpose modules	100
	VME interconnection modules (16)	50
	Interface VME to test computers	50
	Cables, links, networks, terminals, graphic displays	100
	CAMAC modules (CAC, CBA, A2, Branch mixer)	130
TOTAL from CEN Saclay		970
From SERC UK :		
VAX 11/780	computer with	(800)
	Floating Point Accelerator	
	1.25 Mbyte main memory	
	300 Mbyte disk	
	2 x 1600 bpi 45 ips tapedrives	
	300 lpm upper/lower case lineprinter	
	Fisher Camac Interface Suite	
	3 Mbytes main memory	30
	2 6250/1600 bpi Tapedrives	230
	Terminals and interfacing	150
	500 Mbyte disk drive	105
	Network connections (Ethernet?)	90
TOTAL from UK		600
From NRC Canada :		
VAX 11/780	computer with	(600)
	Floating Point Accelerator	
	4 Mbyte main memory	
	2 RUA 81 tri-disc systems	278
	2 TEU 78 6250 bpi Tapedrives	230
	Network connections	22
	High speed line printer/plotter	32
	High resolution graphics terminal	48
TOTAL from Canada		610
TOTAL		2180

21. SERVICES AND FACILITIES REQUESTED FROM CERN

The OPAL Data Collection and Analysis group will require the following facilities at CERN :

i) space/power/service for computer and office/terminal room space both at I6 and on the main CERN site. This has already been specified in the document : Instrument of understanding between CERN and participants in a joint research body to be known as the OPAL collaboration (CERN/EF/161H/JT/ed 24 Nov. 83).

ii) the provision of air conditioned tape storage
   a) for 1000 tapes at IR by 1988
   b) for 10,000 tapes at CC by 1990

iii) the establishment, upgrade and support of the following links
   a) X25 gateway (including file and terminal traffic) now
   b) Local Area Network (LAN) for IR by 1987
   c) CERN backbone Network at IR by 1987
   d) High speed direct link for remote data recording from IR → CC by 1988

iv) the provision and support of an easy-to-use multi-user interactive GRAPHICS general facility by 1986

v) the support for 370/Es.

vi) the gradual acquisition and support of personal workstations over the period 1985-1988, to reach a total of 20 for OPAL by 1989

vii) the provision and support of a bank of main-frame emulators, particularly for Monte Carlo use, by 1987

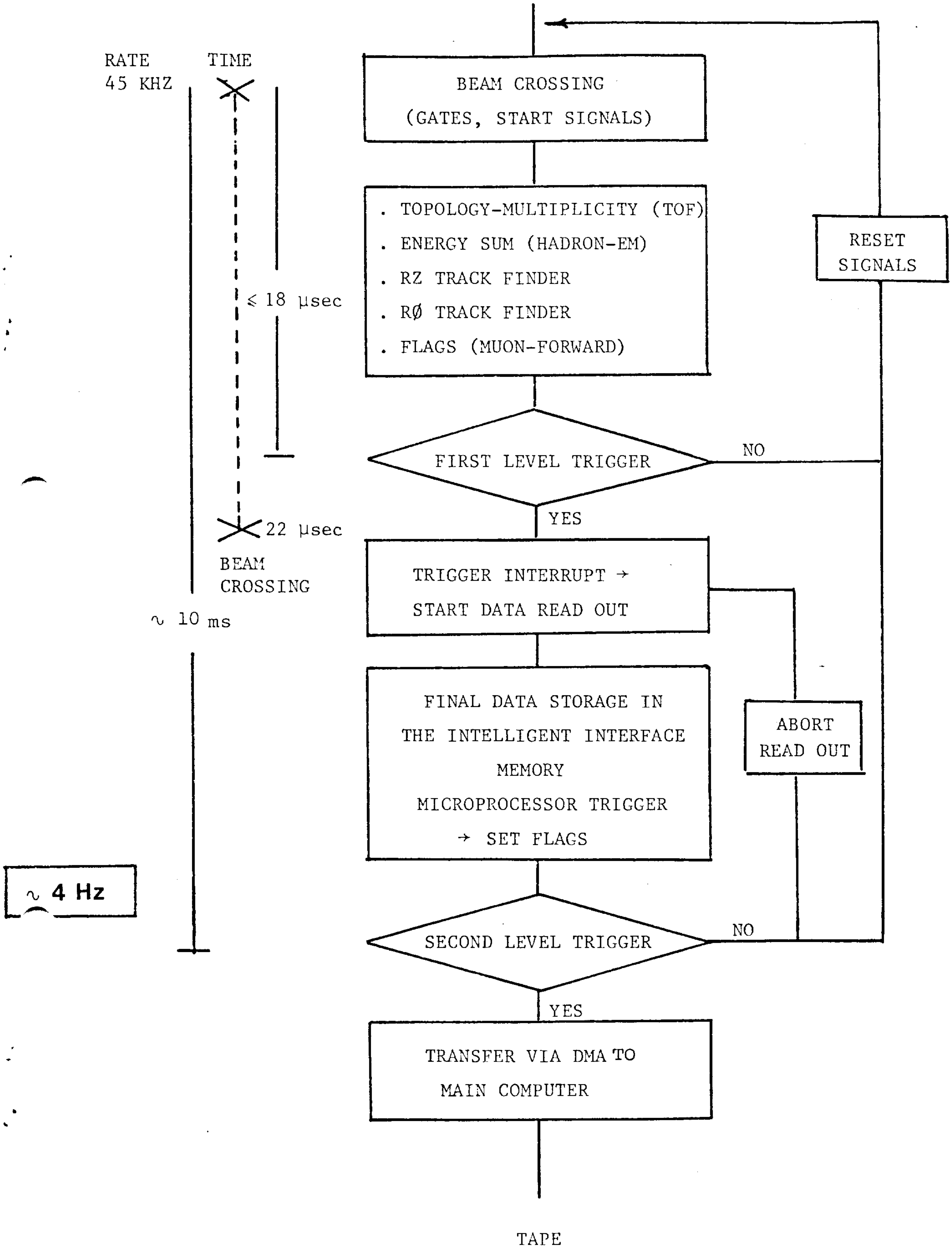
viii) the allocation of central computer time which will increase steadily from 100 hours (IBM 370/168) in 1983 to 40,000 hours in 1990

ix) the establishment of a CERN OPAL software group with
  - a) four senior programmers
  - b) four junior programmers
  - c) two data aides for code documentation/book-keeping functions

x) the services of the CERN on-line computer groups for installation and support of common on-line software both in test beams and in the final experiment.

22. FIGURE CAPTIONS

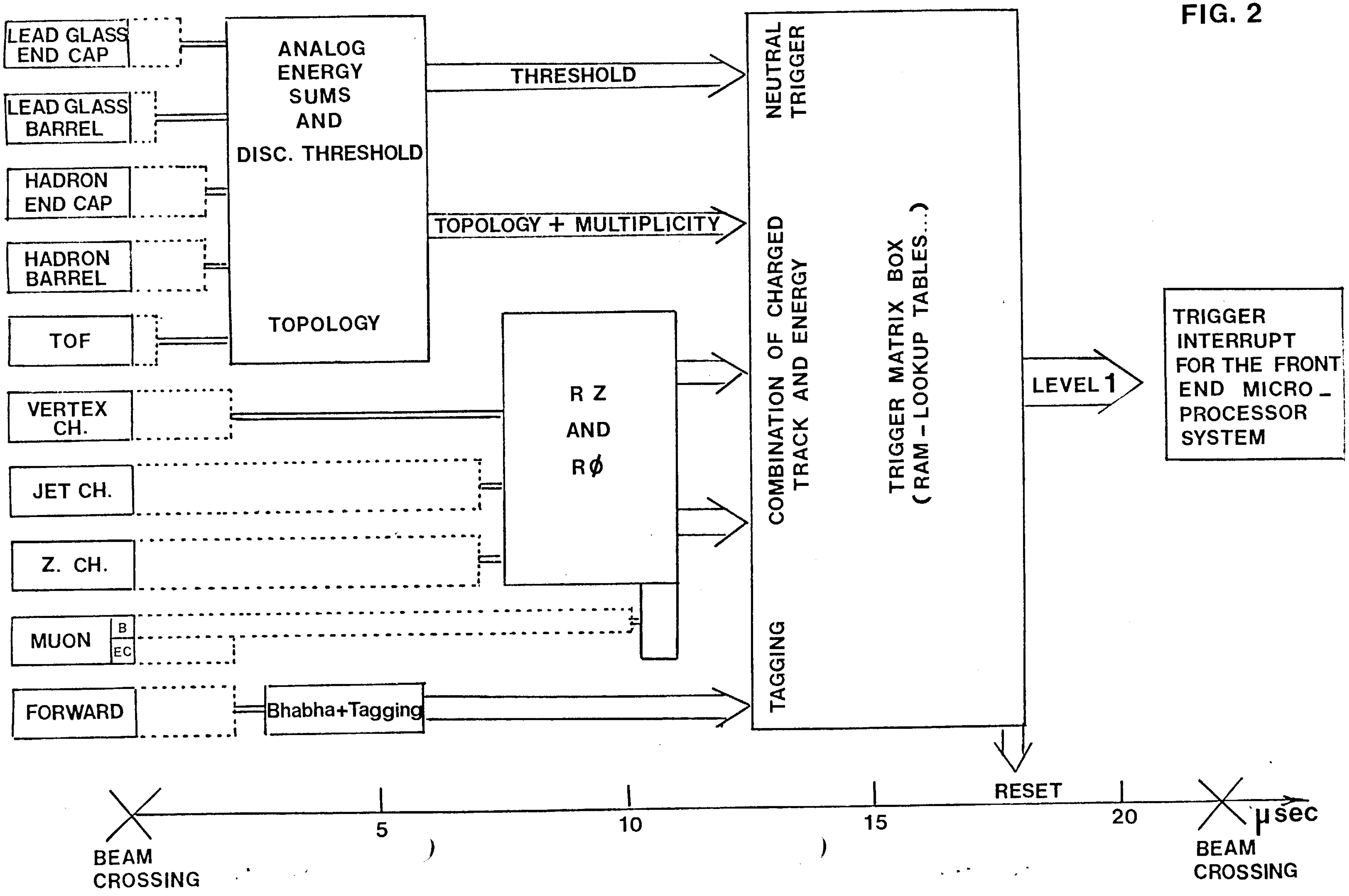
Fig. 1	Flow diagram of triggering information.
Fig. 2	Block diagram of the main components of the OPAL detector showing their time response, type of physics information and input to the trigger system.
Fig. 3	OPAL Data read out diagram.
Fig. 4	View of the OPAL detector in the garage position, showing arrangement of electronic huts.
Fig. 5	OPAL data acquisition location around the detector.
Fig. 6	Graphics display of the OPAL detector.
Fig. 7	Network connections for OPAL.

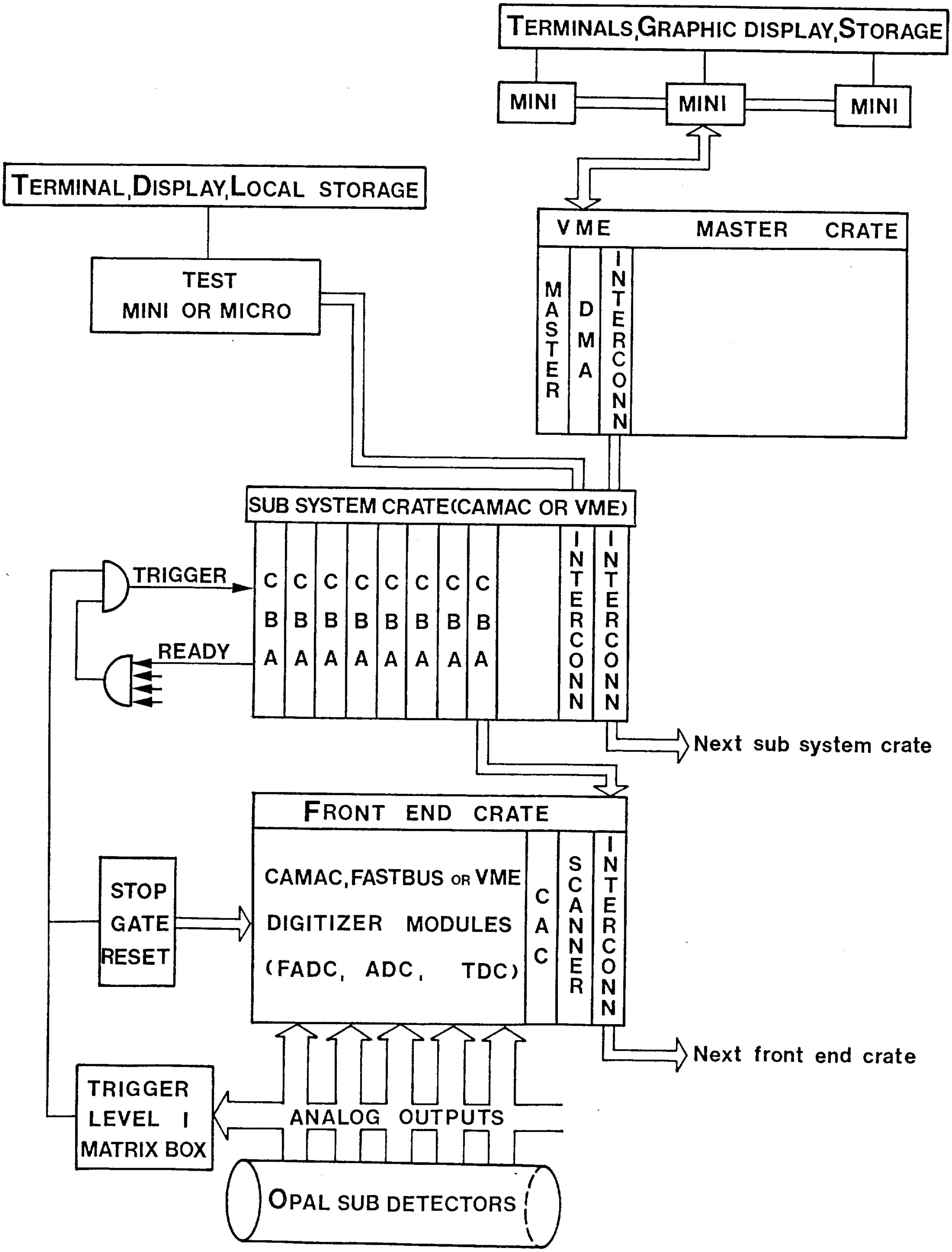


OPAL TRIGGER SCHEME

FIG. 1

FIG. 2

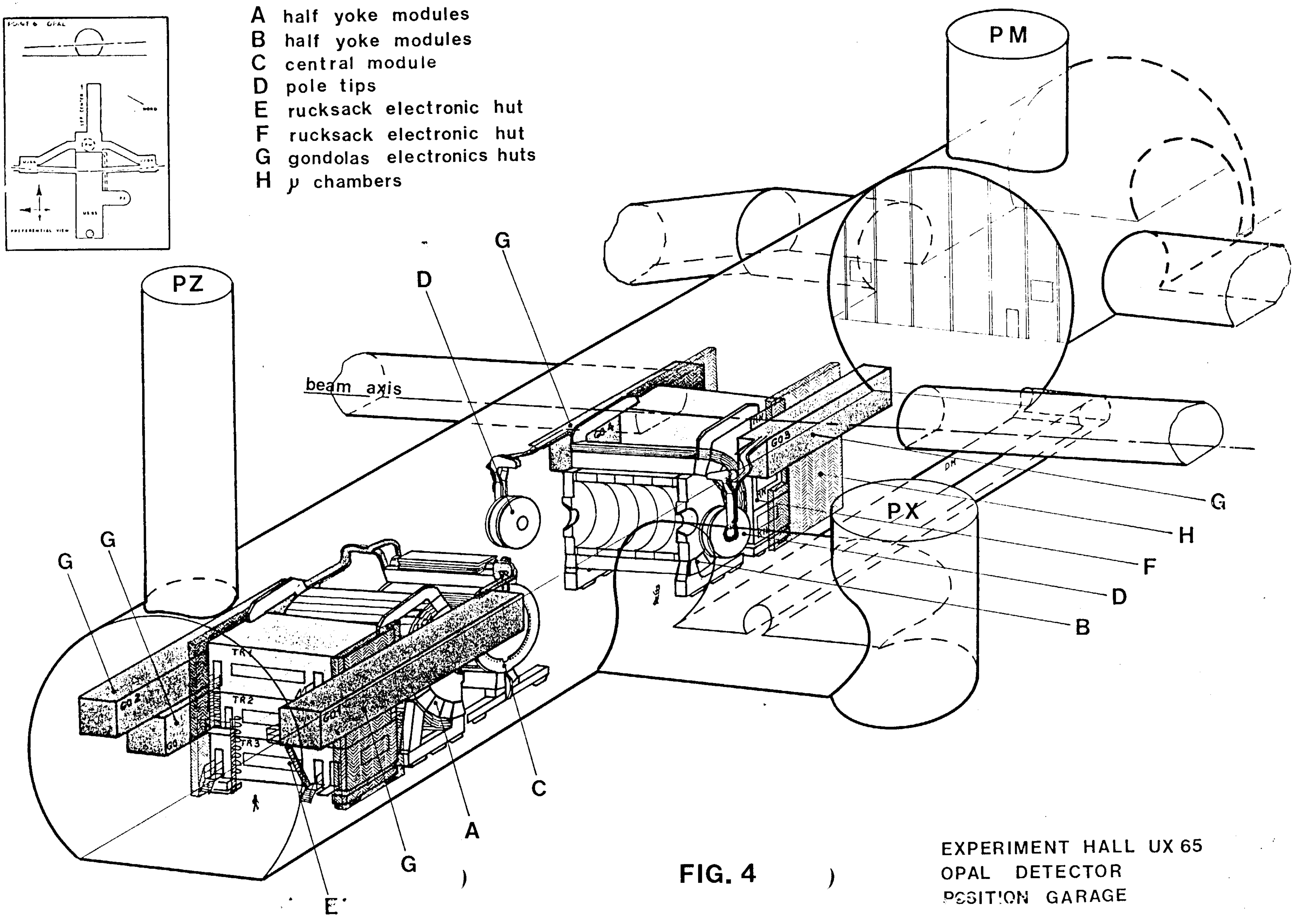

LEAD GLASS END CAP
LEAD GLASS BARREL
HADRON END CAP
HADRON BARREL
TOF
VERTEX CH.
JET CH.
Z. CH.
MUON
B
EC
FORWARD
ANALOG ENERGY SUMS AND DISC. THRESHOLD
TOPOLOGY
THRESHOLD
TOPOLOGY + MULTIPLICITY
R Z AND Rϕ
Bhabha+Tagging
NEUTRAL TRIGGER
COMBINATION OF CHARGED TRACK AND ENERGY
TAGGING
TRIGGER MATRIX BOX (RAM-LOOKUP TABLES...)
LEVEL 1
TRIGGER INTERRUPT FOR THE FRONT END MICRO-PROCESSOR SYSTEM
RESET
BEAM CROSSING
5
10
15
20
BEAM CROSSING
μsec



OPAL DATA READ OUT DIAGRAM

January 1984

FIG. 3



A half yoke modules
B half yoke modules
C central module
D pole tips
E rucksack electronic hut
F rucksack electronic hut
G gondolas electronics huts
H μ chambers

FIG. 4

EXPERIMENT HALL UX 65
OPAL DETECTOR
POSITION GARAGE

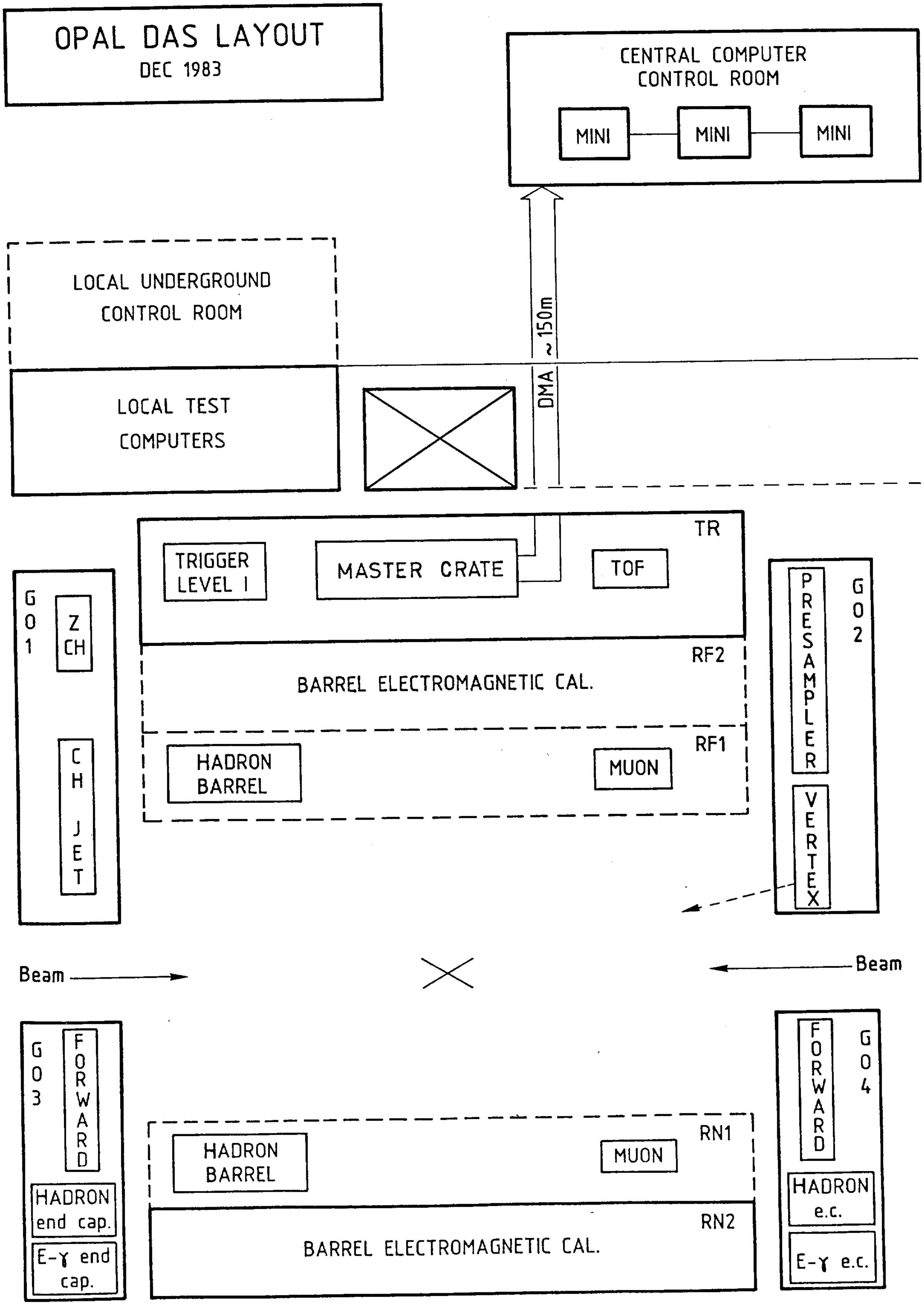

OPAL DAS LAYOUT
DEC 1983
CENTRAL COMPUTER CONTROL ROOM
MINI
MINI
MINI
LOCAL UNDERGROUND CONTROL ROOM
~ 150m
DMA
LOCAL TEST COMPUTERS
TR
TRIGGER LEVEL I
MASTER CRATE
TOF
G 0 1
Z CH
CH JET
RF2
BARREL ELECTROMAGNETIC CAL.
RF1
HADRON BARREL
MUON
PRESAMPLER
VERTEX
G 0 2
Beam
Beam
G 0 3
FORWARD
HADRON end cap.
E-γ end cap.
RN1
HADRON BARREL
MUON
RN2
BARREL ELECTROMAGNETIC CAL.
FORWARD
G 0 4
HADRON e.c.
E-γ e.c.

FIG. 5

OPAL – Front view

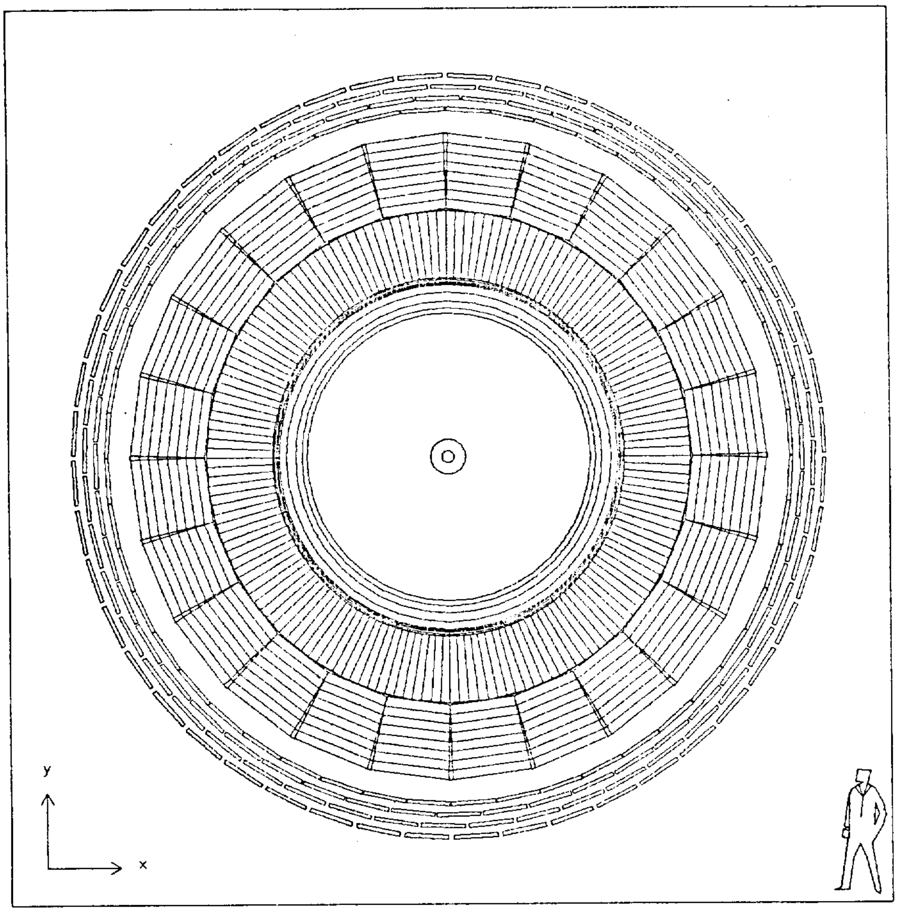
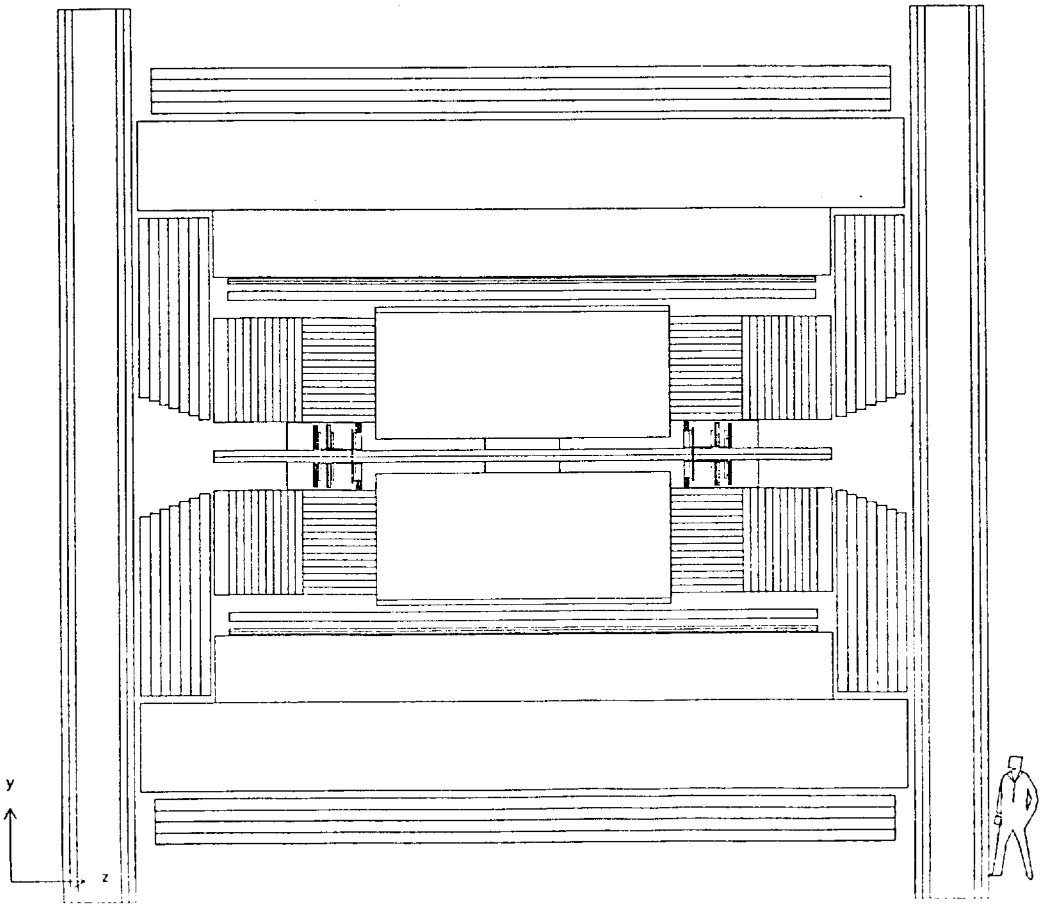


FIG. 6

OPAL – Side view



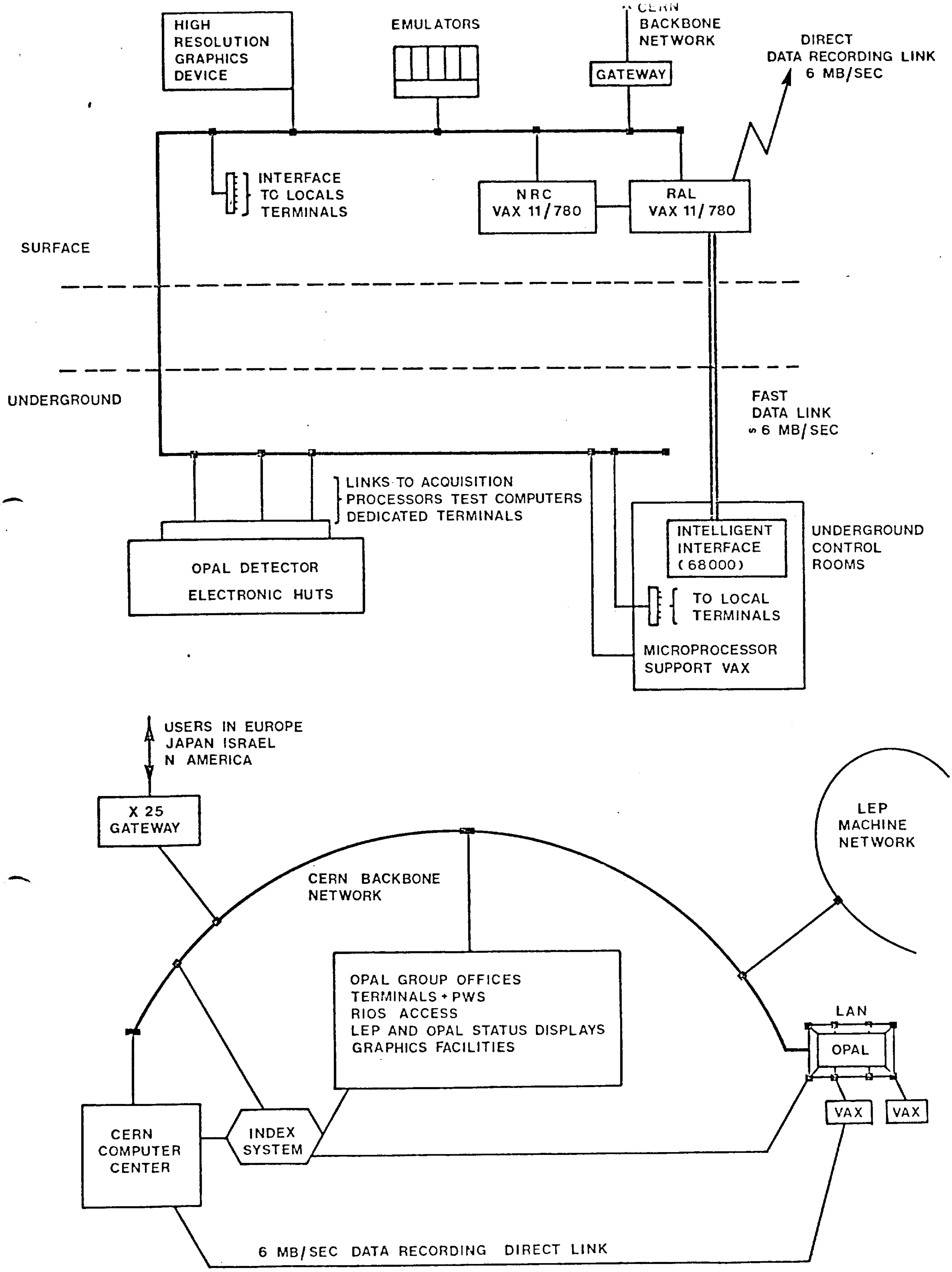


FIG. 7

NETWORK CONNECTION FOR OPAL