III C. Detector Electronics, DAQ, and Relative Timing

Introduction

The physics goals of Experiment 889 impose several requirements for the electronics, such as dynamic range, timing resolution, and event rates. The expected range of signals in a single PMT from neutrino induced events will vary from 0.1 photo electron (p.e.) to 1,000 p.e. An effective dynamic range of 14 bits with a least count of 0.1 p.e. should be adequate for the experiment. Simulations indicate a need for a resolution of $\sigma_t \approx 1$ ns for good vertex resolution. Finally the electronics should handle an instantaneous rate of 100 kHz for brief periods during the AGS spill.

Two other important factors drive the design of the system. First, the system will be widely distributed; two tanks are on site at BNL, 1 km and 3 km from the neutrino production site, while the other two are 24 km and 68 km away. For these last two sites, normal methods of propagating timing signals, such as over coaxial cable or optical fiber, are not practical. Second, the cosmic rate is large compared to the neutrino signal at the far sites. The most effective method for reducing cosmics from the data uses the very narrow time structure of the neutrino beam. Every 1.6 seconds, the AGS will produce a spill of 8 buckets of protons regularly spaced with a period of 335 ns[1] (Figure 1). Each bucket will last 20–30 ns; knowledge of precise event and bucket times at the detectors will allow rejection of all events outside bucket intervals.

An additional consideration is the reliability and remote monitoring of the experiment, since the far and probably the near sites will be mostly unmanned during normal operation.

System Overview

We plan a widely distributed data collection system that consists of these elements:

- A system at the AGS accelerator which generates a *BEAM-ENABLE* gate that is broadcast to the other locations prior to extraction.
- An electronics/DAQ system at *each* detector (tank) which is responsible for reading the tank PMTs during the *BEAM-ENABLE* gate.
- A system at the neutrino production site which yields accurate times of beam buckets.

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[1] The spill length is therefore 2.7 μsec.

- A base station at BNL which collects and collates data from all sites.

The sites local to BNL will be connected by optical fiber links for logic signals and computer networks, but the remote sites (24 and 68 km) will be linked to BNL with microwave communications transceivers that have multiple analog and digital[2] channels. In addition, the neutrino production and all detector sites will be equipped with identical, accurate, GPS-synchronized timing systems. (see Figure 2).

The *BEAM-ENABLE* signal, about 10 μsec in duration, will bracket each spill, preceding the first bucket by 2–3 μsec. It will be transmitted to the detector sites via an analog channel of the microwave communications link. This signal synchronizes data collection with the AGS beam; no events outside this interval will be accepted, so it causes a first-order cosmic-ray rejection based on beam time.

Since the leading edge of the *BEAM-ENABLE* signal indicates that neutrinos are about to arrive, the systems at each tank will start recording all PMT signals above a given threshold for a 10 μsec interval upon receipt of this signal. At these tanks, precise event times will also be recorded using accurate, Global Positioning System-synchronized (GPS) timing systems. Event records will be stored on a local tape drive for backup, and transmitted via a digital link to the base station. At the neutrino production site, the precise bucket times will be recorded using a timing system identical to that at the tanks. These beam times will also be sent to the base station to be collated with events from the detectors.

Generation of *BEAM-ENABLE*

The AGS extraction control mechanism (as illustrated in Figure 3) will be used to generate the *BEAM-ENABLE* signal. In the acceleration cycle, at a preset magnetic field, a signal t_{AGS} is generated. After a predetermined number of orbits, n_{orb}, the beam is extracted. Since each AGS orbit has a fixed period, $\tau_{orb} = 2.6\mu s$, n_{orb} can be adjusted according to the needed delay time.

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[2] EtherNet ready; T1 bandwidth

Table I. Propagation Delays to Sites

Detector	Distance	Light Travel Time
D1	1 km	3.3 μs
D3	3 km	10 μs
D24	24 km	80 μs
D68	68 km	227 μs

The *BEAM-ENABLE* signal needs to be derived before the actual extraction time t_{ext}, and sent to the microwave transmitter. While the travel times to the detectors are quite large (see table I), we only need to be concerned with delays in cables, transmitters, and receivers when broadcasting to the remote detectors, since both the signal and the neutrinos travel at the same velocity. Although the spill duration is 2.7 μsec, a window of 10 μsec will allow detection of μ decays of stopped muons in the tank from either cosmic rays or neutrino events. A jitter of up to 1 μsec is tolerable provided the leading edge sufficiently precedes the actual arrival time of the first bucket.

Detector Systems

The detector systems are composed of five distinct subsystems (Figure 4):

1. **Front end electronics.** The electronics will process the signals from the photomultipliers, measure the signal arrival time at the PMT with respect to the trigger time, digitize all the information and store it in a local memory.

2. **Trigger system.** The trigger system, based on the multiplicity of photomultipliers with signal above a preset level, and coincidence with *BEAM-ENABLE*, will determine if a given event will be readout by the DAQ. It will also allow calibration triggers with pulsers or cosmic rays.

3. **Timing system.** This GPS-synchronized system will allow accurate determination of event time for comparison with bucket times recorded by the AGS Beam History system at the neutrino production site.

4. **Data acquisition system.** For the reading, recording, and transmission to base of all digitizing electronics.

5. **Housekeeping.** This sub-system will keep track of slowly varying detector parameters. It will be used, for example, to monitor the high voltage power supplies.

We discuss these detector subsystems in detail.

Front End Electronics

At each detector there are 2550 20 cm diameter PMTs of which 2200 face inward for the main detector and 350 face outward for the veto shield. It is the task of the front end electronics to digitize amplitude and timing data from the PMTs. The system must also interface with high voltages, since signals arrive on the same cable carrying high voltage to each PMT.

The Choice for the Front End

The electronics chosen for the experiment should be able to handle pulses from the photomultipliers in the range of 0.1 p.e. to 1,000 p.e. This implies a system with a dynamic range of 14 bits. Since digitizers with this many bits are very costly, the feasible option will be to have a system with dual gain, and therefore effectively achieve the needed dynamic range.

The timing constraints, on the other hand, are dependent on the position resolution to determine the location of the neutrino interaction. Monte Carlo simulations indicate that for a position resolution of the order of 20 cm we need a timing resolution of 1 ns per PMT. Since the PMTs can inherently achieve this timing resolution or better, the electronics must not deteriorate it further.

Table II. Expected number of raw neutrino events per spill at the detector sites

Site	$\nu_\mu n \to \mu^- p$	$\nu_e n \to e^- p$	$\nu N \to \nu N \pi^0$	Total Rate
D1	.51	5.1×10^{-3}	0.10	0.86
D3	5.7×10^{-2}	5.7×10^{-4}	1.1×10^{-2}	9.7×10^{-2}
D24	8.9×10^{-4}	8.9×10^{-6}	1.8×10^{-4}	1.5×10^{-3}
D68	1.1×10^{-4}	1.1×10^{-6}	2.2×10^{-5}	1.9×10^{-4}

The electronics must be able to handle the event rate which in our case is from two sources: neutrino induced events and cosmic rays. The flux of cosmic rays is 80 kHz. However, since we will run synchronously with the accelerator our concern is only with the number of events occurring in the time window when the data acquisition is operational. The *BEAM-ENABLE* window of 10 μsec implies that the contribution from the cosmic rays to the number of events within the time window will be ~1 per pulse on average. The rate of real events will depend on the detector distance to the accelerator and it is summarized in Table II, assuming 2×10^7 spills over 16 months. Consequently, the effective rate that we need to handle will be 1–2 events per single AGS macro-cycle of 1.6 sec, or of the order of 1 Hz. For each hit PMT the data packet will consist of the charge and time, channel address, global trigger, and appropriate flags giving a total of approximately 10 bytes. An average event involves 400 hit PMT; therefore the total event size will be approximately 4 kilobytes. The highest event rate will be in D1 and will be less than 2 events per spill, yielding less than about 10 kilobytes per second.

With the above requirements in mind we have chosen to use the existing electronics design of the Sudbury Neutrino Observatory (SNO) [1] for each of the four independent detectors. The performance specifications of the SNO electronics are listed in table III.

Table III. SNO Electronics Performance Specifications

time resolution	< 1.0 ns.
charge resolution	~0.1 p.e.
maximum charge	~1000 p.e.
trigger deadtime	none
low energy throughput rate (continuous)	1 kHz

The SNO front end electronics are designed for a wider dynamic range than is needed for E889, and have excellent timing resolution. Furthermore it can sustain a rate of 1 kHz and bursts of up to 1 MHz, which are also more than adequate for the present experiment. Finally, it is designed, costed, and will be tested by the time E889 will need to commence construction.

SNO Electronics Overview

The SNO system is packaged in custom VME (9U) crates with modified backplanes which hold 16 Front End cards and one Trigger Card (see Figure 5). The Front End cards handle signals from 32 PMTs each, and interface with a larger trigger system through the Trigger Card. When the Front End cards receive a Global Trigger (GT) through their Trigger Card, they digitize amplitude and time information for all PMTs above a given threshold, and store the data in a dual port memory which can be read through the backplane by a standard VME master. The back of the crate also houses 16 High Voltage cards, each of which supplies power to 32 PMTs. The signals and high voltage are carried on a single cable to each PMT connected to the rear of the crate. Since each SNO crate can handle up to 512 PMTs, we will use 5 crates at each detector, which will be connected to a VME Master Crate with VME memory mapped repeaters.

The major signal processing elements of the Front End cards are (1) a wide dynamic range integrator, (2) a fast, sensitive, discriminator and timing circuit, and (3) an analog/digital pipeline memory, all of which are full custom, application specific, integrated circuits. These handle all of the analog signal processing except for the analog to digital conversion. The logic diagram for one PMT channel is shown in Figure 6 and the block diagram of the basic electronics setup for a detector is shown in Figure 7.

High Voltage Distribution Cards

The high voltage part of the electronics crates consists of 16 cards, 32 channels each, with a common distribution card for each crate. The HV is provided for each crate from five commercial regulated bulk supplies that can supply 100 mA at 3.0 KV. Each HV supply can be controlled and read back from the SNO crate controller. The raw HV will be distributed to the crates from these supplies and each crate can provide power for 512 PMT's. The HV card, in addition to providing high voltage, will AC-couple the analog signal to the Front End card. These cards will sit on the rear of the electronics crates back to back with the Front End Cards, sharing PMT signals via a common P2 connector.

The Front End Cards

The Front End card receives 32 PMT signals and will discriminate, store, digitize, and buffer the time and charge information. The card consists of two different custom bipolar front end integrated circuits (SNOINT and SNOD), a custom CMOS timing and analog pipeline integrated circuit (QUSN6), commercial ADCs, memories, standard logic and programmable logic devices.

Each bipolar chip set (SNOINT and SNOD) has four complete channels, each of which contain: two self gating integrator (HI/LO) channels, a fast discriminator and a timing sequence with three programmable intervals. Shown in Figure 8 are the chip level blocks and connections for a single PMT input. The charge gain is determined by the size of the external integration capacitor chosen for each channel and the relative attenuation ratio between the two dual ranging channels is set by external resistors. A signal is detected by a fast discriminator on the SNOD chip that monitors the PMT activity. The SNOD chip fires the discriminator if the differentiation of the input pulse exceeds an externally applied threshold. The threshold can be set to any range and to effectively turn off a channel one only needs to set this value very high. The discriminator is optimized to give a very fast response time and low walk and jitter. The SNOINT chip controls the actual charge integration with an effective dynamic range of more than 14 bits. A charge integration is triggered by a signal over threshold in the SNOD chip discriminator. The SNOD chip provides two gating functions for the SNOINT chip, called RESET and SAMPLE. The RESET signal controls the charge integrator reset switches, and is used to initiate a time measurement cycle and to provide primitive system triggers. The SAMPLE signal controls the separate recording of charge from the instantaneous and reflected photons. The outputs of the SNOINT & SNOD are the signals from the high and low integrator sections of SNOINT and the SAMPLE and RESET from the SNOD. These signals are presented to QUSN6. The SNOINT and SNOD chipset is fabricated in AT&T's advanced, fully custom, high speed CBICU-2 process.

QUSN6 provides three charge and one time analog memory, time to amplitude conversion (TAC), and channel and trigger logic for the detector. A single channel timing sequence is shown in Figure 9. On the leading edge of a RESET signal a timing cycle and TAC is initiated. The TAC for any PMT can be stopped by a centrally generated Global Trigger (GT) signal. The charge integral measurement voltages, low and high gain, from SNOINT are sampled on the leading and trailing edges of the SAMPLE signal. If a GT trigger arrives from the central trigger system before an internal time-out is reached, the four analog voltages are stored in one of the 16 analog memory banks and a digital memory records the sequence number of the GT, the memory location, and any set condition flags. If no GT arrives before the internal time-out is reached, the channel resets itself and is ready to accept another PMT input. Therefore, the dead time will be the per PMT dead time of one GT timing sequence that can be set to allow for light reflection across the E889 detector volume. In addition to this FIFO like data path, the QUSN6 chip includes a trigger generation function, some basic utility functions, and self-test capability. To keep independent track of PMT noise rates and error conditions, separate internal counters are used for the RESET signal. All of the latches and counters are accessible for testing and programmable adjustments for fine tuning the TAC slope are built in.

The write process into the analog memory is data driven by a coincidence of a PMT signal and a GT pulse. The readout sequence from the analog memory is a separate and asynchronous process. The channel voltages stored in QUSN6 are buffered out of the chip and are fed into commercial 12 bit 2 μsec ADC's for digitization. The output of charge and time ADC's go to a large local buffer memory on the card which acts like a FIFO. The ADC outputs, the channel address, global trigger, and appropriate flags comprise a 12 byte data packet for a particular PMT event and is loaded into the onboard memory. The memory is standard SIMM DRAM and can be read out via the modified VME backplane by a crate master. The three word data structure for each PMT is shown in Figure 10 along with the data flow diagram.

The Trigger Card

The trigger is formed in stages by doing a local Front End Card sum of the 32 channels and then a crate sum of the 16 front end cards. The leading edge of the RESET signal from the SNOD chip in the Front End Card is used in QUSN6 to initiate a pair of digitally programmable current pulses. The longer pulse approximately 100 ns is sent to the first stage of a 2195 input analog sum. This first stage which basically sums up the individual 32 channels on a front end card is implemented using a high speed operational amplifier located on the front end card and shown in Figure 11. This output is sent via the backplane to the crate trigger card which then sums the 16 individual front end cards in its crate to form a signal whose amplitude is proportional to the number of PMT hits in the crate. This Crate Trigger Signal is then sent to the Trigger System (see below) which will decide whether or not to distribute a global trigger back to all the Crate Trigger cards, based upon the presence of *BEAM-ENABLE*, number of hits from the other SNO crates, as well as any other logic decisions we may wish to apply. Upon receipt of GT, the Crate Trigger cards initiate data read cycles.

Trigger

The basic trigger for the experiment at each site will be based on the multiplicity of phototubes above certain threshold (Figure 12). Therefore a basic trigger will simply be some number of PMTs going off simultaneously within some timing window. This timing window will be approximately equal to the transit time of light across the detector. The tanks are approximately 15 m across and it takes light about 60 ns to travel that distance in water so a trigger resolving time of about 100 ns will allow time enough for all the photons from the Cherenkov radiation to be counted towards a trigger. Since this coincidence does not present a sharp edge it will not be appropriate for timing measurements. We will generate a sharp edge timing signal artificially using the logical *and* of the coincidence signal and a 200 MHz clock signal (see next section). The arrival of light at the PMT is measured with respect to the clock edge.

In addition to the event trigger we will make use of other triggers such as calibration, random and cosmic trigger to monitor the performance of the detector.

Timing System

Accurate timing of events will be achieved using Global Positioning System (GPS) receivers. Using averaging techniques and ensuring that receivers which are geographically separated track the same satellite above the horizon (Common View Mode[2]), relative timing accuracies of less than 10 ns can be achieved. The 10 ns synchronization error will most likely be the maximum possible error, rather than a Gaussian distributed error. Given the 12 hour orbit of each GPS satellite it is possible that we observe a worsening in the timing during periods when the GPS receivers are locking to a new satellite, but this should take only a few seconds.

For DAQ the time of the event will be stored in two scalers. One that will be counting the 10 MHz signal from the GPS receiver which is equipped with either a Cesium or Rubidium clock. This will provide us with a timing mark accurate to 100 ns. A second oscillator with higher frequency conditioned by the GPS 10 MHz signal will provide a fine grain timing information. A 200 MHz crystal oscillator will be used for this purpose. Upon the decision by the trigger system that a valid event happened in the tank both values will be recorded. Both scalers, with enough bits to run for one day, will be reset at 0.00 hours based on the GPS 1 pulse per second accurate signal. See also Appendix I.

Computers

Readout of the SNO electronics will be easily handled by a VME Single Board Computer (SBC), *i.e.* a Motorolla 68040, running a real-time kernel such as OS-9. This SBC will sit in the VME Master Crate which is connected to the SNO crates via a memory mapped VME repeater chain. This repeater gives the SBC direct master control of the SNO crates. When triggered by a VME interrupt generated from trailing edge of the *BEAM-ENABLE* signal arriving from the AGS, it will read all individual PMT data packets from the onboard memory, collected by the SNO electronics during the *BEAM-ENABLE* window, and will also record the digital time from the accurate timing system described above.

In addition to PMT and timing data, housekeeping and controls information will also be recorded, as well as any additional electronics (CAMAC scalers, etc.) output. Data will be written immediately to a DAT tape (for backup) but will also be transmitted to a nearby RISC workstation for local monitoring and subsequent retransmission to a base station at BNL. At the base station, there will be a high-end RISC computer that collates and re-formats event records from the individual sites on the basis of the digital time-stamps.

While a telecommunications company can provide a T1-style data link to the remote sites, we currently favor a TCP/IP-ready microwave electronics system, since we will deliver the *BEAM-ENABLE* signal from the AGS to the remote sites via a microwave link in any case. In addition to analog channels, microwave transceivers typically provide more than one T1 channel, allowing extensive two-way traffic for remote monitoring, control, and software development without degrading performance of the primary data path.

Housekeeping

Since the detectors will be unmanned for most of the time it is important to monitor each detector and its associated electronics from the base station. For each site we will implement a monitoring system to read quantities such as the water temperature, high voltages, water level, etc. This information will be available in the network together with the regular data stream and recorded on tape. This system will not handle the alarm system but will be only used to monitor the conditions at different sites.

Beam History at the Neutrino Production Site

The precise micropulse time will be generated from a VME-based multihit TDC placed near the beam dump station, D0. The multihit TDC will be recording the timing difference between the AGS extraction signal and the time muons arrive at scintillator pads located near the beam dump, t_μ. The TDC start time will be also be measured with respect to a GPS-synchronized timing system like those at the detectors. This information will be recorded to give us a time history of the AGS beam buckets. ¿From this record, we can produce a history of bucket arrival times at the detector sites, allowing an effective time cut to be made on background events.

Summary of Section III C.

This section has described the detector electronics, relative timing of the several detectors and the AGS, and the distributed data collection system for E889. This system is planned to run synchronously with the AGS extraction cycle, and requires a bi-directional communication system in which the timing signal from the accelerator is propagated to the detector sites and digitized data returned to a base station at BNL.

In considering the choice of the front end electronics we have opted to use the same system as that designed for the SNO detector. In spite of the differences in the event rates between our detectors and SNO, the synchronous mode of operation should easily provide for use of the SNO electronics in E889. By choosing this particular front end we profit from an existing design. SNO is scheduled to start taking data in 1996 and therefore most of the front end electronics will be available to us by the end of 1995.

The estimated rates for the cosmic ray background should not present a problem in the synchronous running mode. Estimates indicate that with a 10 μs gate to enable the DAQ at every site, the background rate is a few Hz. The timing signal is distributed to all sites by means of microwave links. To the far sites we would allow a timing jitter of about 1 μs which should not be a problem. The same microwave link will be used for digital communications. Since we do not expect rates higher than 10 kbytes/sec from each site this link should be more than adequate for the transmission of digitized data from the distant sites. Data from all sites will be collated at the base station in BNL. However each site will have its own tape to backup the local data.

Finally, a comment on our estimated timing resolution. Since the current plan is to use GPS receiver systems to time each event we expect a resolution less than 10 ns. This resolution is not to be confused with the PMT resolution which will be of the order of 1 ns. While we present here our current idea of how to assign a time stamp to each event, we are pursuing other options. These are detailed in appendix I.

APPENDIX I: Other Avenues for Accurate Timing

We expect a resolution of less than 10 ns from our baseline GPS-based timing system. However, it is our understanding that this value may be significantly reduced. We are therefore studying other approaches in the hopes of further improving the timing resolution and present three here:

- **Direct Transmission of the AGS Beam Time Signal**: The Division of Time, Frequency, and Lasers of the National Institute in Science and Technology (NIST) at Colorado presently maintains nanosecond-level synchronization between atomic clock standards in Boulder and Europe via a microwave satellite link. To achieve a sharp pulse edge, they use a spread-spectrum Ku and C band modem, and to monitor and adjust for propagation delay variations, they employ a technique of simultaneous two-way time transmission at both sites. Since we plan microwave links for the transmission of the BEAM-ENABLE signal for computer telecommunications, we are investigating these methods to see if they can be employed by us between sites.

- **Geostationary Satellite Services**: To prevent accurate positioning of commercial GPS receivers, the high precision bits of the broadcast signal are intentionally encrypted so that non-military systems only obtain the time to within $\sim$100 ns. While the techniques of averaging and running simultaneous systems in Common View Mode can increase this, a problem remains of time loss when satellite re-acquisition occurs.

  We are investigating timing receiver services which use an alternative satellite system, called INMARSAT, which is launched and maintained by an international consortium for the purposes of accurate navigation. This system presents no intentional degradation of accuracy; timing resolutions of 5 ns are possible. Furthermore, these satellites are *geostationary*, so there is no problem of satellite loss and re-acquisition. We are currently in contact with a manufacturer who could provide us with receivers for this system in the very near future.

- **Full GPS Access**. The dithering of GPS timing information on the civilian channel is referred to as Selective Availability or SA. Another avenue that we will explore is the possibility of obtaining access to full information from the GPS satellites. We have learned that the CASA (Cosmic Air Shower Array) detector can achieve 7 ns resolution using GPS with no SA.

APPENDIX II: Physical Layout and Power at Each Detector Site

Each site will have 5 electronics crates holding the Front End Cards, the High Voltage Cards, and a Crate Trigger card. The electronics crates will be controlled by the Master Crate at each site.

Power Requirements

Each detector will have approximately 2550 PMTs to be readout and and supplied with high voltage. At each detector site there will be:

1. 5 electronics crates :

   16 High Voltage Cards per crate with 32 channels each

   16 Front End Cards per crate 32 channels each

   1 on-board repeater per crate

   1 Trigger Control Card per crate

2. 1 DAQ system (or Master Crate):

   1 on-board computer with tape drive and hard disk

   1 Global Trigger Card

   1 Global Timing Card

   1 GPS Timing System

3. 4 Low Voltage Power Supplies,

4. 5 High Voltage Power Supplies.

There will be six racks per detector location. Four electronics racks containing 2 electronics crates (512 PMT channels per crate) for a total of 1024 PMT channels per electronics rack, the low voltage power supplies, the Master Crate, and one NIM bin. The High Voltage Supplies will occupy one rack, as will the DAQ system.

The total power needs for each detector location is approximately 5 kilowatts, which is slightly higher than the SNO numbers because of some duplication of the control electronics. If allowance is made for growth in the system, the power needs should not exceed 7000 Watt per site.

References

[1] D.F. Cowen, T. Ekenberg, J.R. Klein, F.M. Newcomer, R. Van Berg, R.G. Van de Water, P. Wittich, A. Biman and R.L. Stenson. *The Sudbury Neutrino Observatory Electronics Chain*, IEEE Trans. on Nucl. Science (1995), in print.

[2] C. Chen, *Common View Mode GPS Test Data*, DATUM INC., Anaheim, California 92806-5790.

Figure Captions

Figure 1. Structure of the Fast Extracted Beam (FEB) from the AGS and the BEAM-ENABLE gate. In the FEB running mode the AGS macro cycle is 1.6 s. Each spill consists of 8 buckets 30 ns long and spaced by 335 ns. The Data Acquisition System will be enabled for a 10 μs long gate which brackets the 2.7 μs long AGS beam spill.

Figure 2. Overview of the Distributed E889 Data Acquisition System. The BEAM-ENABLE signal will be propagated to the detector sites over microwaves. Digital data from detector sites will be collated at the Base Station using fiber optics and microwave network links. Each site will be equipped with a precision oscillator synchronized by GPS receivers to provide a time stamp for each event.

Figure 3. The AGS Extraction Timing. During the AGS acceleration cycle t_{AGS} signal is generated. An integer number of orbits after its generation the beam will be extracted.

Figure 4. Overview of the detector DAQ system.

Figure 5. SNO Electronics packaging. The Front End Cards will be housed in custom 9U VME crates. The Trigger card sits in the center of the crate and interfaces to the F.E.C via the backplane. Each Front End Card (F.E.C.) connects to 32 PMTs trhough the backplane P2 connector. P3 provides links to trigger and VME Master. P1 is the High Voltage bus.

Figure 6. The Logic Diagram for one PMT Channel. Each PMT is connected to the system via a single Coaxial Cable. The signal is decoupled from the High Voltage by a capacitor at the input of the preamplifier. The preamplifiers are followed by custom design integrated circuits to digitized and store charge and time measurements.

Figure 7. Front End Electronics setup at one detector.

Figure 8. Block Diagram of the SNO bipolar chipset, SNOD and SNOINT.

Figure 9. Single Channel timing cycle for the SNO front end electronics.

Figure 10. The on board data flow from the PMT inputs to the VME interface and a table of the three word data structure for a single PMT hit.

Figure 11. The layout of the PMT-Sum for trigger generation.

Figure 12. Schematic of the trigger system.

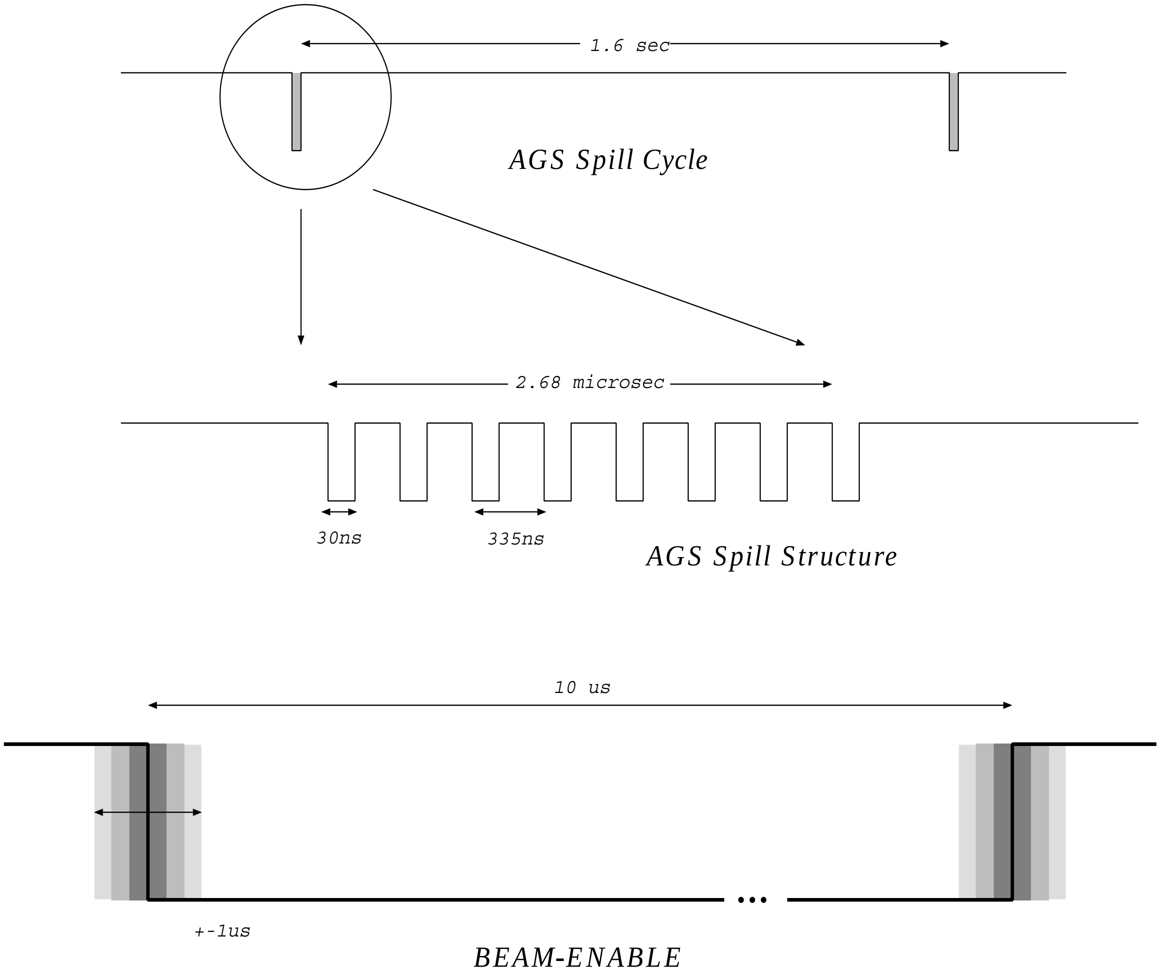

1.6 sec
AGS Spill Cycle
2.68 microsec
30ns
335ns
AGS Spill Structure
10 us
...
+-1us
BEAM-ENABLE

Fig. 1

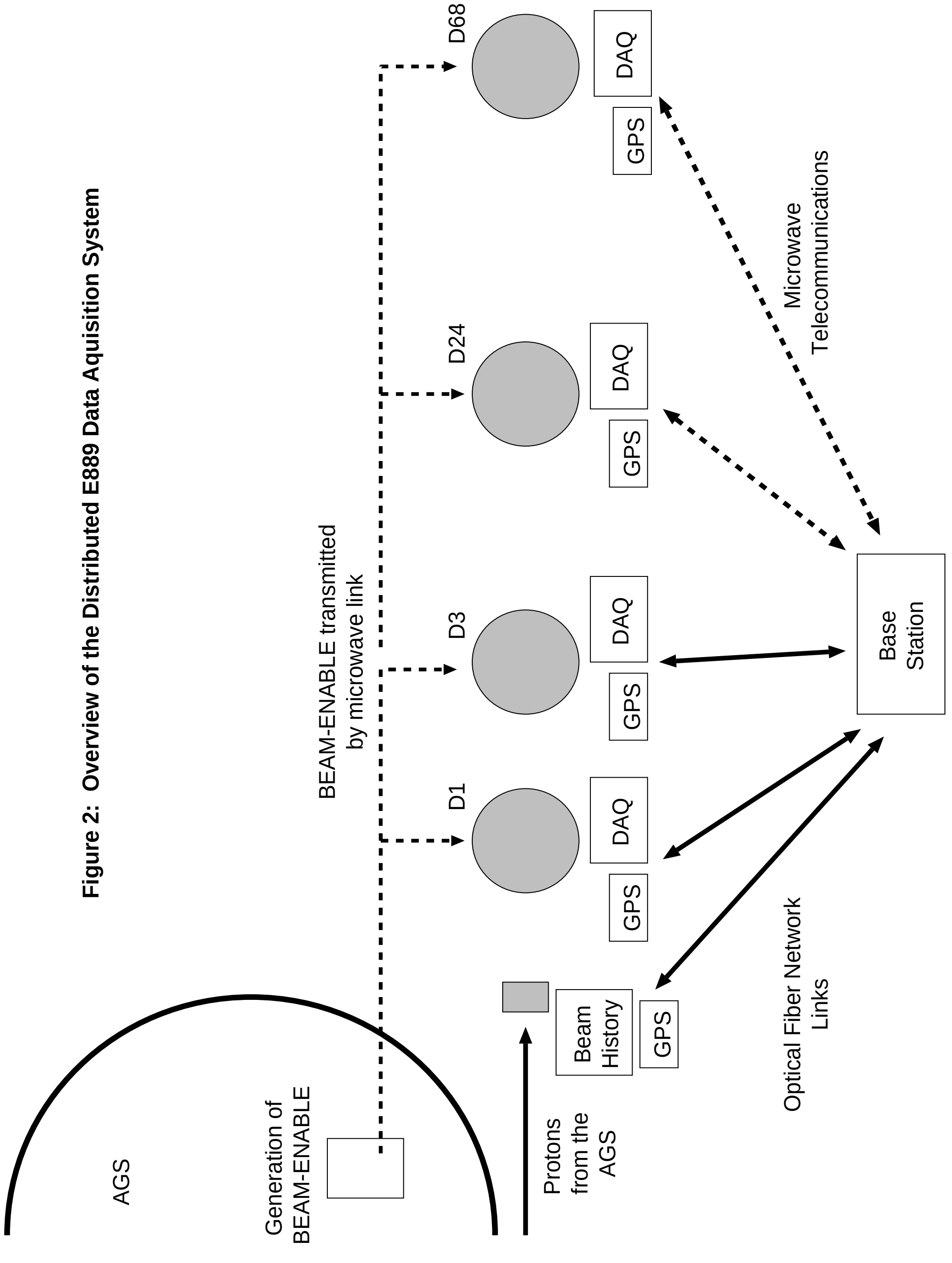
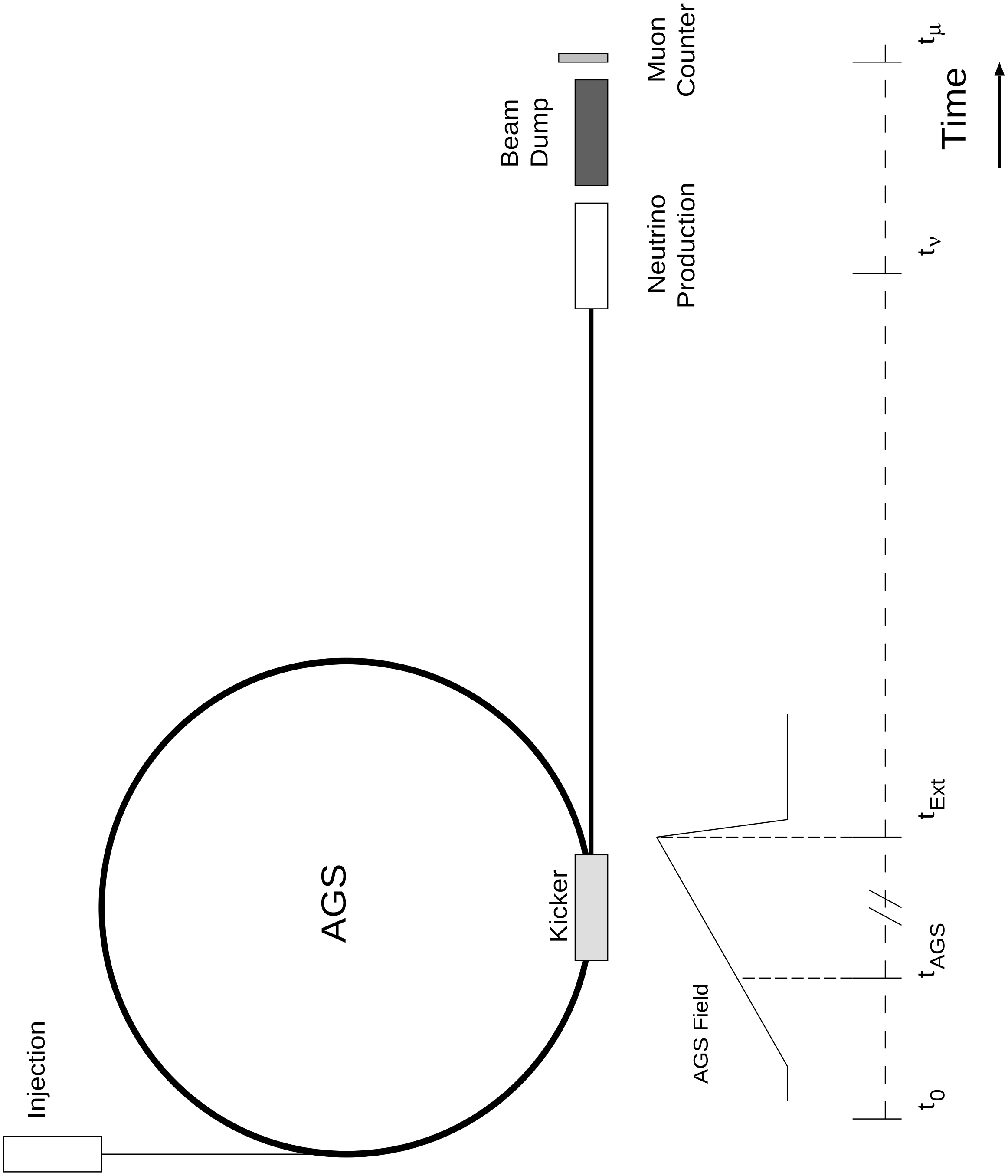


Figure 2: Overview of the Distributed E889 Data Aquisition System

Fig. 2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AGS
Kicker
AGS Field
t_0
t_{AGS}
t_{Ext}
Neutrino Production
Beam Dump
Muon Counter
t_ν
t_μ
Time

Fig. 3

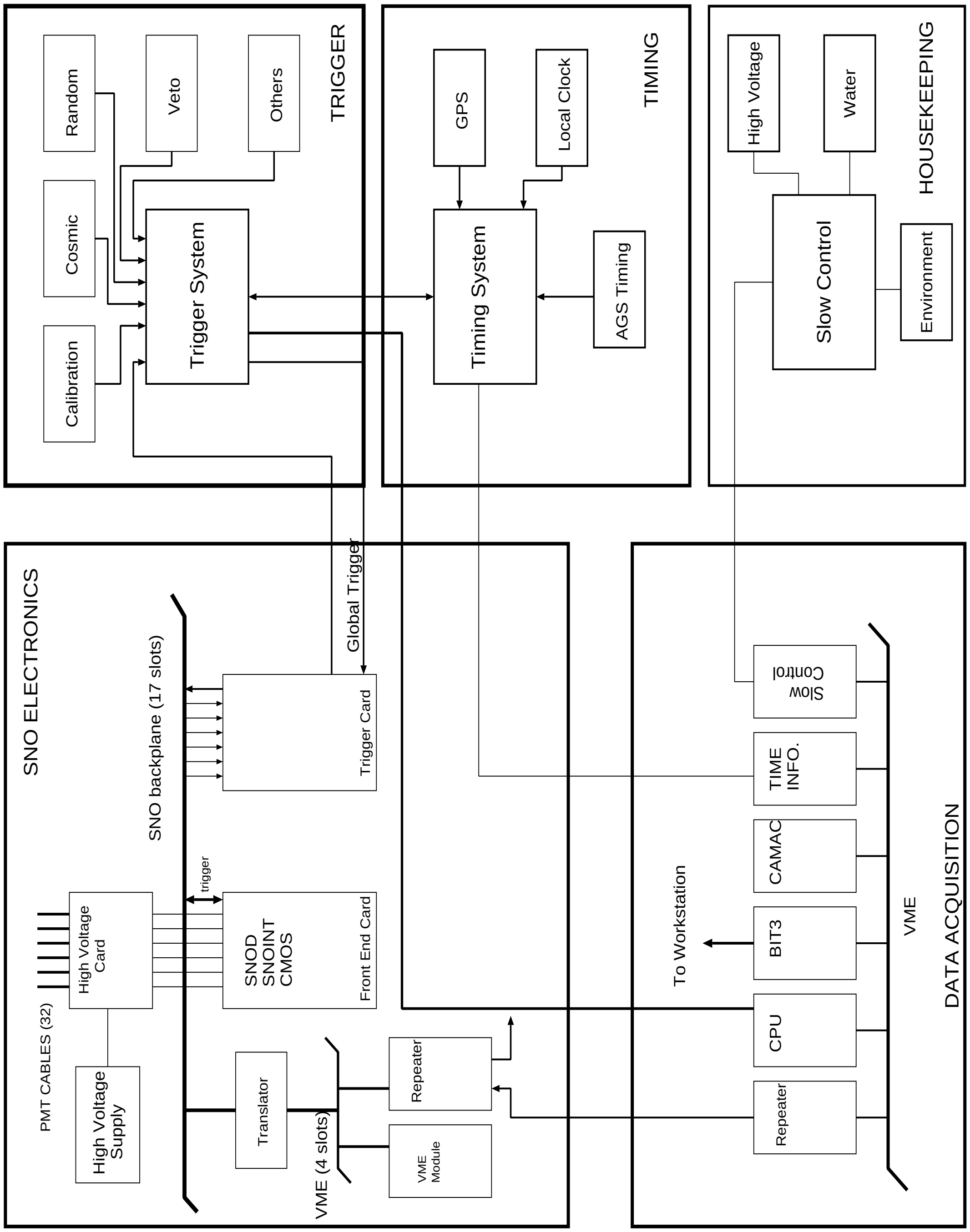
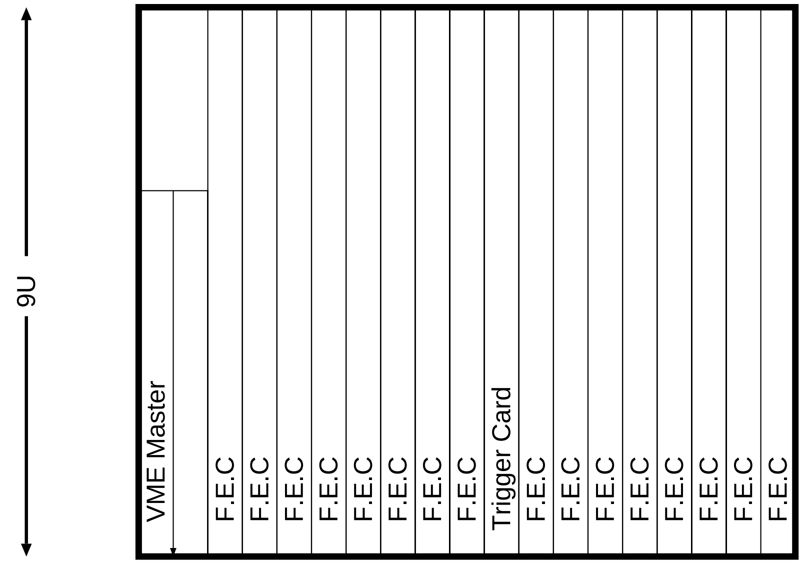

TRIGGER
Random
Veto
Others
Cosmic
Calibration
Trigger System
TIMING
GPS
Local Clock
Timing System
AGS Timing
HOUSEKEEPING
High Voltage
Water
Slow Control
Environment
SNO ELECTRONICS
SNO backplane (17 slots)
Global Trigger
Trigger Card
trigger
High Voltage Card
SNOD
SNOINT
CMOS
Front End Card
PMT CABLES (32)
High Voltage Supply
Translator
VME (4 slots)
Repeater
VME Module
DATA ACQUISITION
Slow Control
TIME INFO.
CAMAC
BIT3
CPU
Repeater
VME
To Workstation

Fig. 4



SNO Electronics Crate
Front View

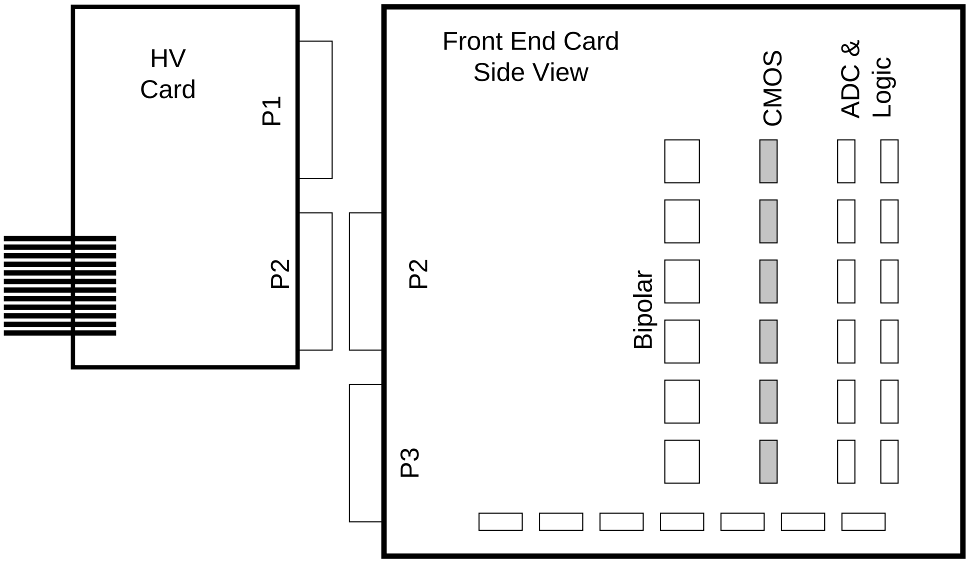


Fig. 5

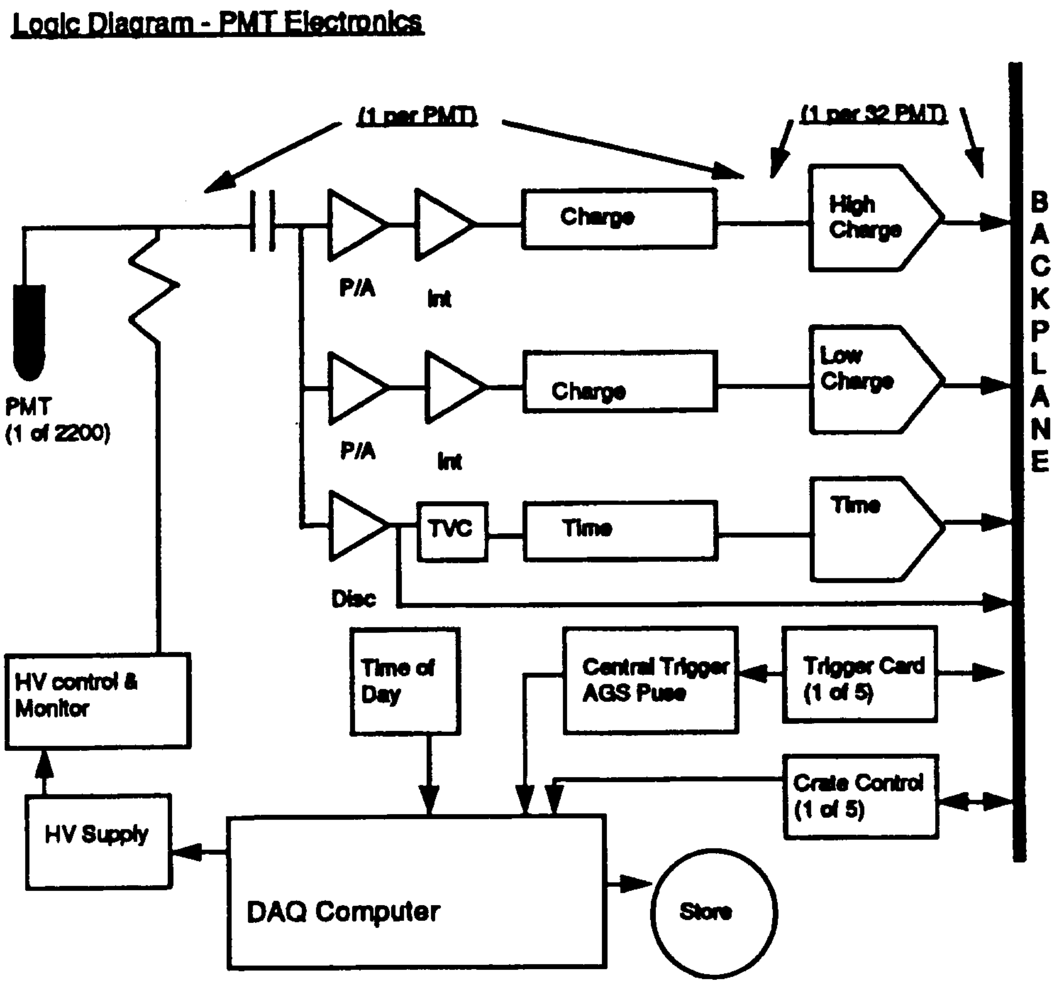
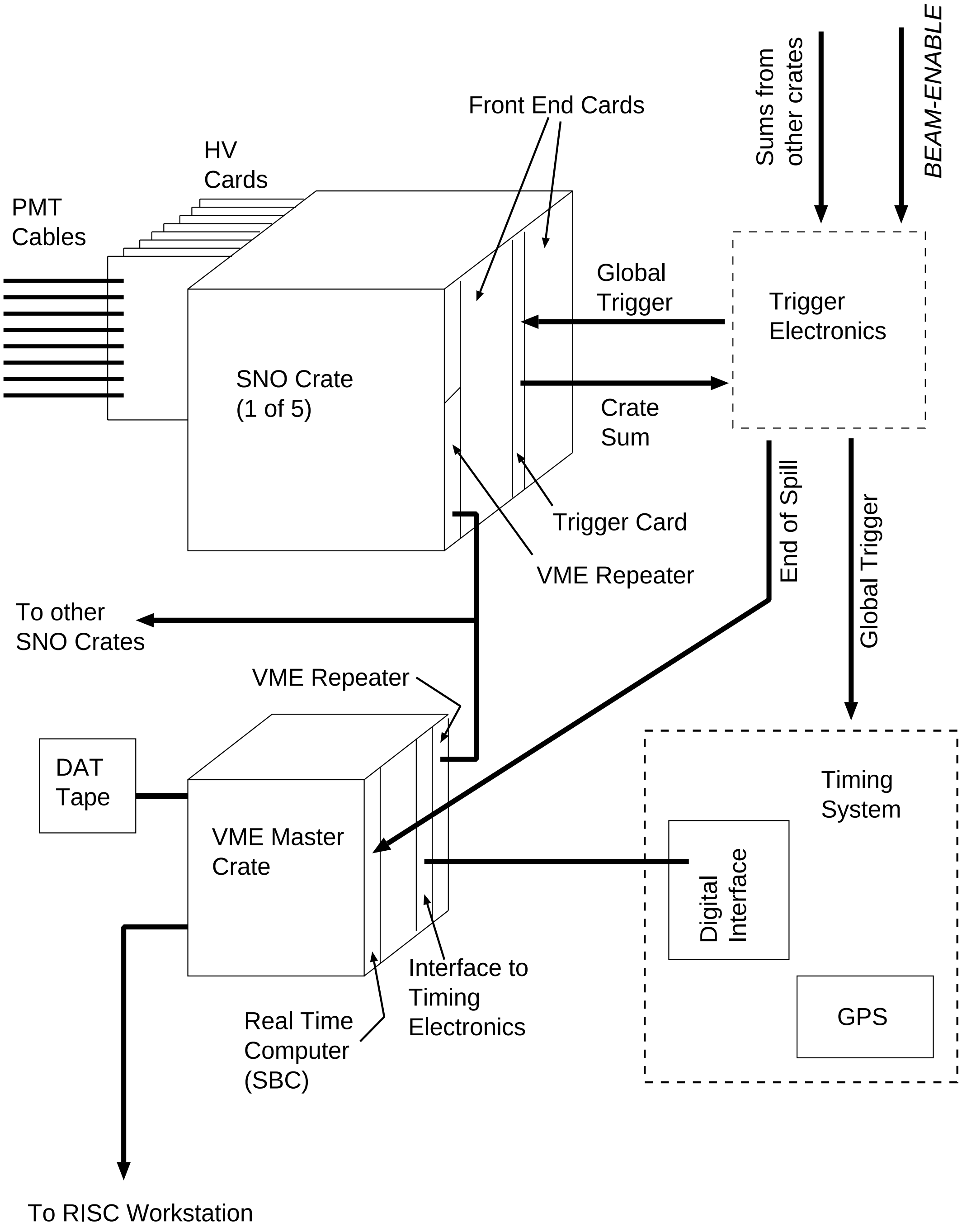

Logic Diagram - PMT Electronics
(1 per PMT)
(1 per 32 PMT)
PMT
(1 of 2200)
P/A
Int
Charge
High Charge
P/A
Int
Charge
Low Charge
Disc
TVC
Time
Time
B A C K P L A N E
HV control & Monitor
Time of Day
Central Trigger AGS Puse
Trigger Card (1 of 5)
Crate Control (1 of 5)
HV Supply
DAQ Computer
Store

Fig. 6



Sums from other crates
BEAM-ENABLE
Front End Cards
HV Cards
PMT Cables
Global Trigger
Trigger Electronics
SNO Crate (1 of 5)
Crate Sum
Trigger Card
VME Repeater
End of Spill
Global Trigger
To other SNO Crates
VME Repeater
DAT Tape
VME Master Crate
Timing System
Digital Interface
Interface to Timing Electronics
Real Time Computer (SBC)
GPS
To RISC Workstation

Fig. 7

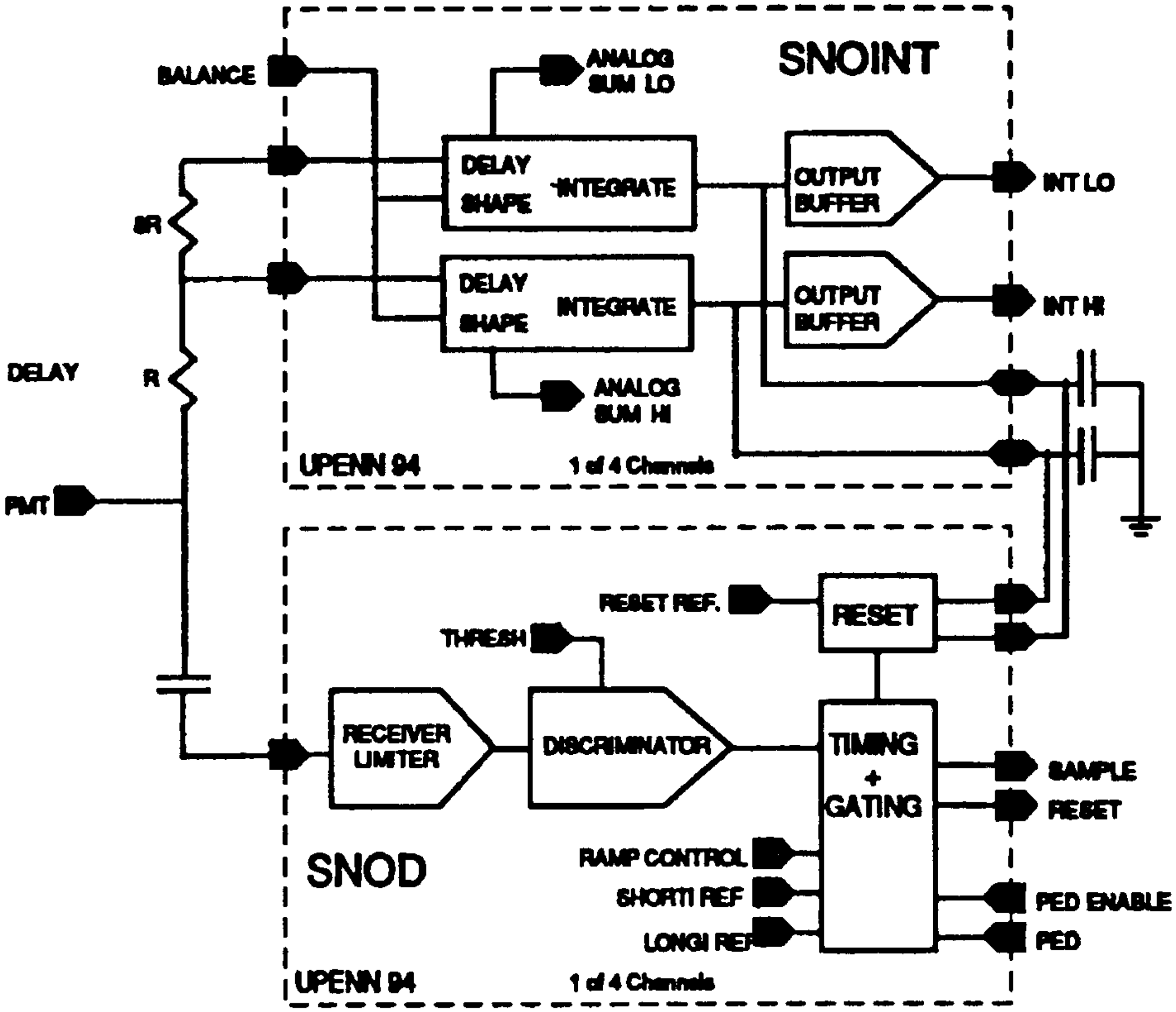

BALANCE
ANALOG SUM LO
SNOINT
DELAY
SHAPE
INTEGRATE
OUTPUT BUFFER
INT LO
8R
DELAY
SHAPE
INTEGRATE
OUTPUT BUFFER
INT HI
DELAY
R
ANALOG SUM HI
UPENN 94
1 of 4 Channels
PMT
RESET REF.
RESET
THRESH
RECEIVER LIMITER
DISCRIMINATOR
TIMING + GATING
SAMPLE
RESET
SNOD
RAMP CONTROL
SHORTI REF
LONGI REF
PED ENABLE
PED
UPENN 94
1 of 4 Channels

Fig. 8

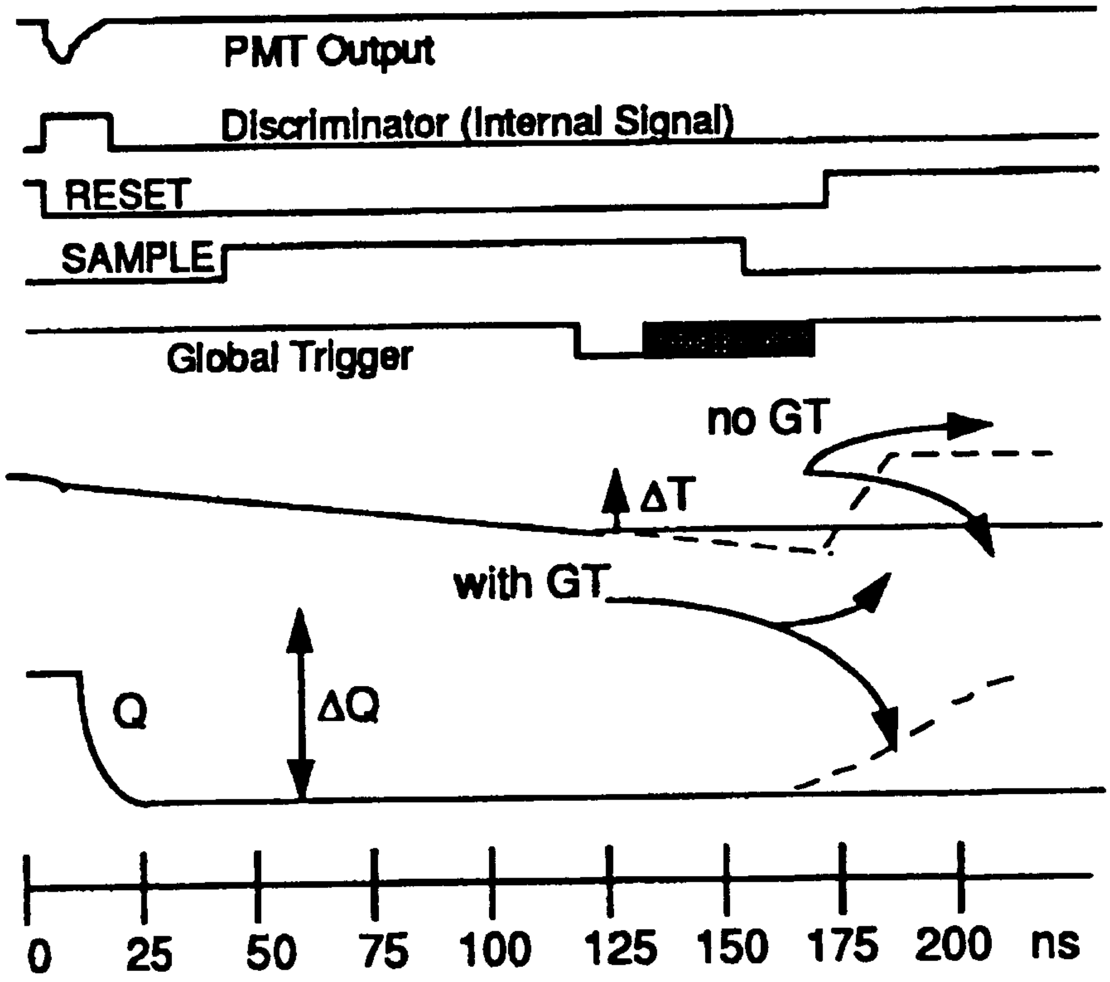
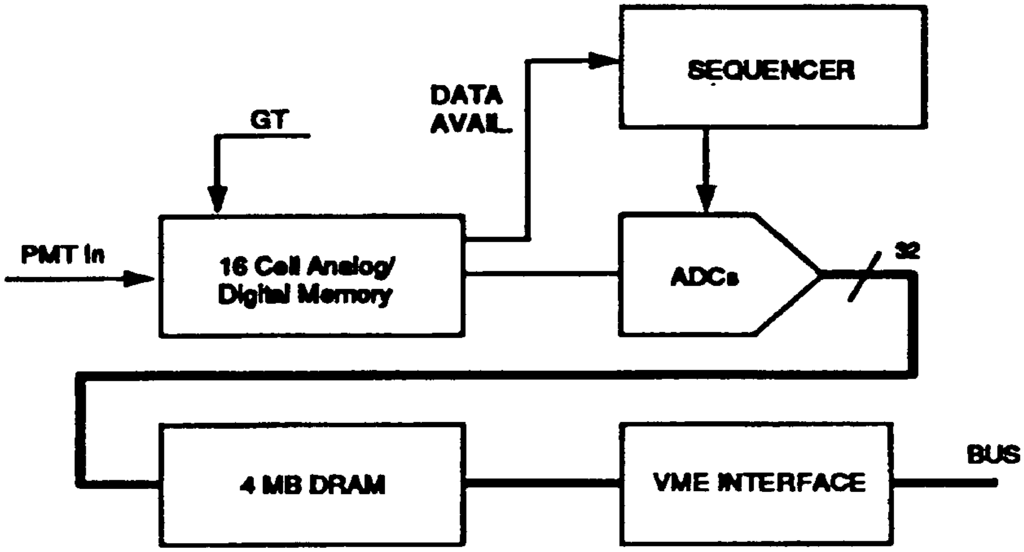

PMT Output
Discriminator (Internal Signal)
RESET
SAMPLE
Global Trigger
no GT
ΔT
with GT
Q
ΔQ
0
25
50
75
100
125
150
175
200
ns

Fig. 9



The Three Word Data Structure Table

1	Flag 2	Crate + Channel 5 9	Trigger Identifier 8 8
2	Err 4	QLoLong 12	Flag QHiLong 4 12
3	Cell 4	TAC 12	Flag QHiShort 4 12

Fig. 10

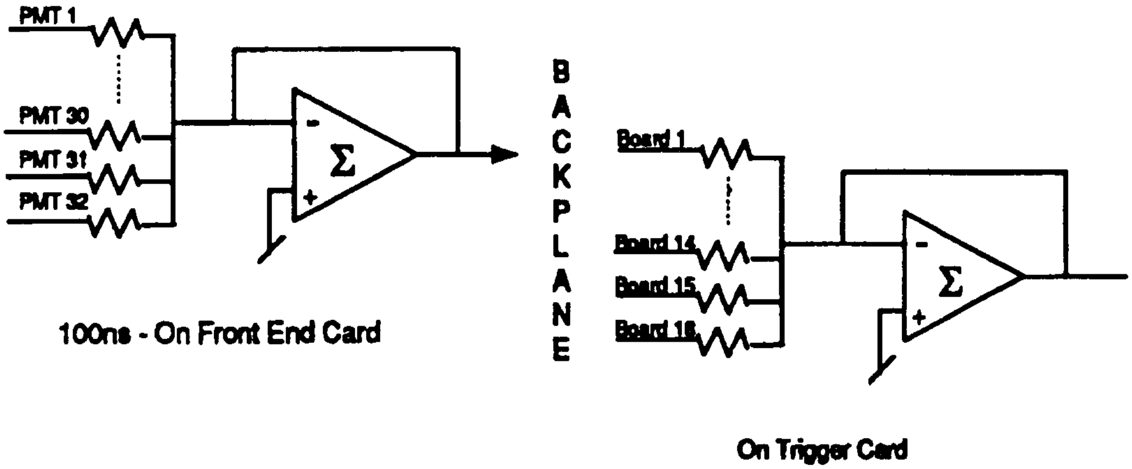

PMT 1
PMT 30
PMT 31
PMT 32
-
+
Σ
100ns - On Front End Card
B
A
C
K
P
L
A
N
E
Board 1
Board 14
Board 15
Board 16
-
+
Σ
On Trigger Card

Fig. 11

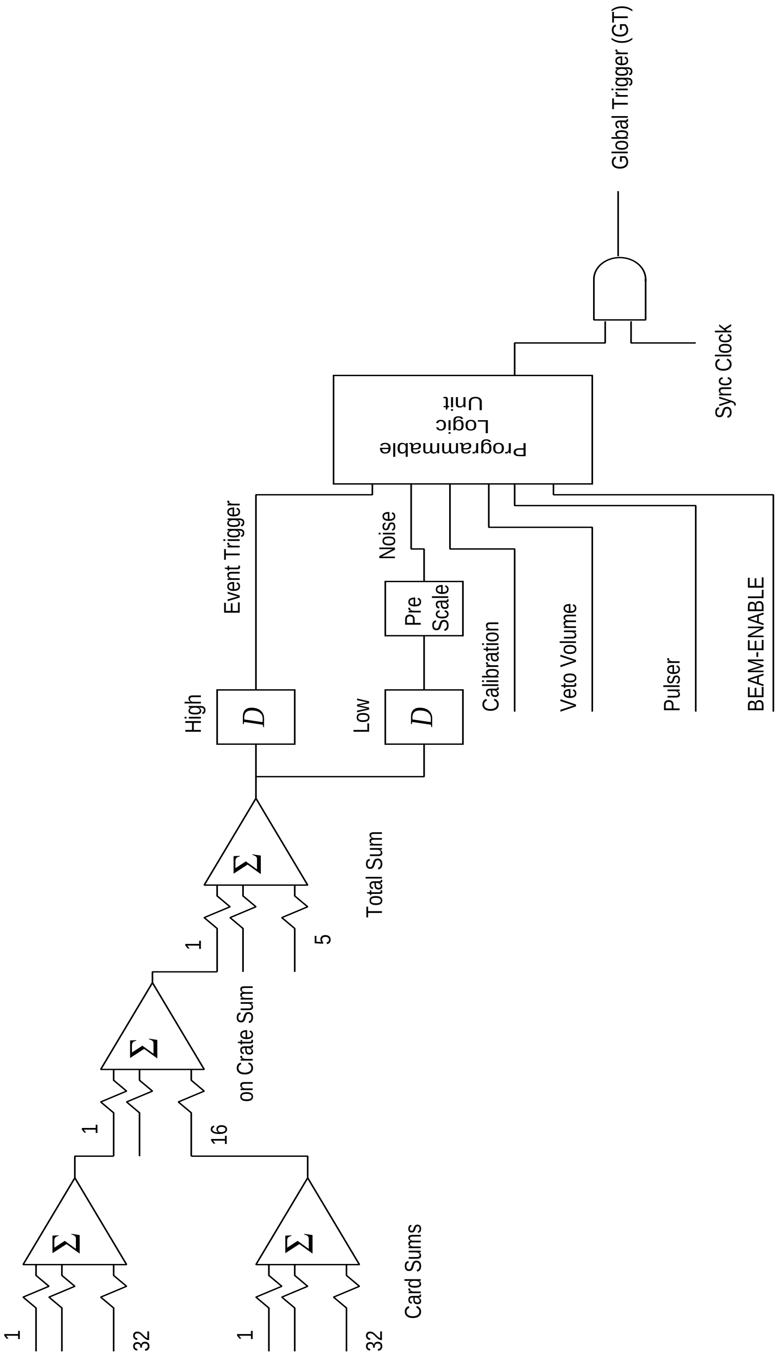

1
32
1
32
Σ
Σ
Card Sums
1
16
Σ
on Crate Sum
1
5
Σ
Total Sum
High
D
Low
D
Event Trigger
Noise
Pre Scale
Calibration
Veto Volume
Pulser
BEAM-ENABLE
Programmable Logic Unit
Sync Clock
Global Trigger (GT)

Fig. 12