TRI-PP 83-43

Paper presented at the Conference on Real-Time Computer Applications in Nuclear and Particle Physics, Berkeley, CA, May 16-20, 1983.

TRI-PP-83-43
May 1983

THE TRIUMF TIME PROJECTION CHAMBER DATA ACQUISITION SYSTEM

R. Poutissou, G. Azuelos, J.P. Martin and P. Depommier
Université de Montréal, Montréal, P.Q., Canada H3C 3J7

A. Bennett, A. Burnham†, D.A. Bryman*, W. Dey, C. Irwin, M. Leitch*, J.A. Macdonald, I. Navon*, T. Numao, J.M. Poutissou†, P. Schlatter*, J. Spuller
TRIUMF, Vancouver, B.C., Canada V6T 2A3

M. Hasinoff
University of British Columbia, Vancouver, B.C., Canada V6T 2A6

M. Dixit, C.K. Hargrove, H. Mes
National Research Council of Canada, Ottawa, Ont., Canada K1A 0R6

M. Blecher, K. Gotow
Virginia Polytechnic Institute, Blacksburg, VA, USA 24061

A.L. Carter, W.R. Jack
Carleton University, Ottawa, Ont., Canada K1S 5B6

Summary

The Time Projection Chamber (TPC) at TRIUMF was developed for the search for muon-electron conversion, a lepton number violating process. This paper describes the data acquisition system in use for the last two years. Basic components of the system are a multi-crate CAMAC acquisition system, external memory, PDP 11/40 and VAX 11/780 coupled through DECNET. A discussion of the various software packages for data-taking and on-line track reconstruction follows.

Introduction

A Time Projection Chamber (TPC)[1] is a large volume drift chamber with parallel uniform electric and magnetic fields. The magnetic field bends charged particles so that their momenta may be determined and the electric field causes the ionization electrons to drift towards the position sensing devices.

Such an apparatus was developed at TRIUMF to search for muon number violation in the reaction μ^-+nucleus $\rightarrow$ e^-+nucleus, in which a single 100 MeV electron track is detected following nuclear muon capture event. Rare process searches require the largest possible detection solid angle and the most efficient use of maximum beam current because scans through large candidate sets are required. The goal of this experiment is to reach a sensitivity on the branching ratio of 10^{-11}-10^{-12}. Thus at least 10^{+13} incident muons have to be investigated.

The experiment was designed to use a continous muon flux of up to 1 million particles/second produced by pion decay near the production target in the primary proton beam of 100 μA of the TRIUMF continous duty-cycle cyclotron. With an efficient trigger system that would eliminate unlikely candidates, the actual number of events to be recorded was expected to be less than 10/second.

Detection and Trigger System

The TRIUMF TPC (Fig. 1)[2] is a 69 cm long drift chamber placed inside a uniform magnetic field. A central high voltage plane produces a uniform electric field parallel to it. The two hexagonal end caps are divided into six sectors. Each one consists of twelve slots, each containing an anode wire and a series of segmented cathode pads. As the drifting track reaches the end caps, each wire will detect a segment of that track. The position of the wire gives the Y coordinate, the distribution of the charge on the segmented

*also at the University of Victoria
†also at the University of British Columbia

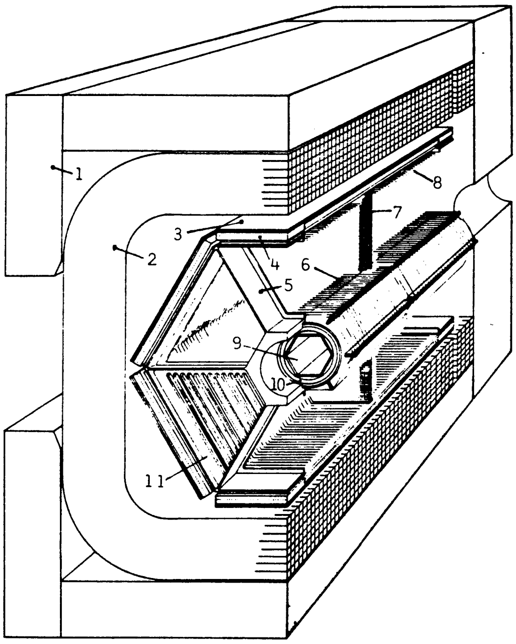

Fig. 1. A perspective view of the TPC. The numbered elements are: 1) the magnet iron, 2) the coil, 3) outer trigger scintillators, 4) outer trigger proportional counters, 5) endcap support frame, 6) central electric field cage wires, 7) central high voltage plane, 8) outer electric field cage wires, 9) inner trigger scintillators, 10) inner trigger cylindrical proportional wire chamber, 11) endcap proportional wire modules for track detection.

pads gives the X position along the wire and the drift time of the track, together with the known drift velocity in the gas, will give the Z coordinate.

All 144 anode wires (12 wires on each of 12 sectors) are read out individually, whereas the 636 pads per sector are multiplexed. The anode and pad signals are digitized using a LeCroy 2280 scanning ADC system. It consists of a CAMAC based auxiliary processor with pedestal memory for each channel of 12-bit ADC modules, 48 channels to a module and of a common gate. Modifications have been made to the ADC modules to provide each one with its own gate.

The processor can be operated in absolute mode where each ADC value is read out, or in pedestal subtraction mode where only channels over a certain threshold after pedestal subtraction are read out. There is provision to read a fixed number of channels on either side of the ones which have exceeded threshold.

With this read-out system, the signals can be digitized only once per event, so only a single track can be seen. The time information is recorded using TDC's on the signals from the anode wires.

Muons from the beam are stopped in a long target centered in the middle of the TPC and produce mainly low energy electrons below 53 MeV. The magnetic field is set so that only electrons with energy greater than ~60 MeV can reach the outer trigger detectors. Scintillation counters and wire chambers are placed on the inside and outside cylindrical walls of the TPC on each sector. These counters provide signals for fast logic decisions. Since the electrons of interest should reach the outside of the TPC, the fast logic looks for a coincidence between a selected combination of inner and outer counters for 600 nsec after the arrival of each beam particle. If a valid coincidence is found during this time, all the recording electronic modules and the TPC read-out system are enabled for a maximum time equal to the drift time from the center of the TPC to the end caps. This is of the order of 5 μsec.

There is a further logic check to see if a minimum number of wires in the TPC have sufficient data. This last check determines if the event is good or not. If it is not, a reset pulse is sent to all modules and the detection of beam particles is enabled within 15 μsec. If it is good, a LAM is sent to the computer and all information from the CAMAC crates is read except the one from the LeCroy 2280 ADC system because of its slow conversion time of around 2 μsec. Upon end of conversion, the ADC system will send its own LAM to initiate data transfer.

To test the functioning of the TPC, cosmic rays and laser pulses are used. To calibrate the solid angle and the detection efficiency, monoenergetic positrons of 70 MeV/c from the pion decay $\pi^+ \rightarrow e^+ + \nu_e$ are recorded. All these cases require different trigger conditions. For example, cosmic rays are so energetic that they hardly bend in the magnetic field and they cross the chamber in an almost straight line. MB10/6†† programmable logic units have been used as the core of the fast and slow logic. With these CAMAC units it is possible to quickly change the trigger conditions by loading them with different patterns.

Hardware

When the experiment was designed, two minicomputers, a PDP 11/40 and a Data General NOVA 820 were available. It was felt that the whole data acquisition process should be separated between those two computers. One would be dedicated to recording all the data onto magnetic tape and controlling the experiment with the smallest dead time possible. The other would process a sample of events at random to extract some information like the momentum of the particle that produced the track, its angle of emission, etc, in order to monitor the experiment.

Figure 2 describes the data acquisition system as it is now configured.

The experimental data signals are fed to modules housed in six CAMAC crates. All are part of a CAMAC parallel branch highway serviced by a Fisher (formely GEC Elliott) system crate. This system was chosen because, at the time, it was the only one able to support access from two computers. The system crate was equipped with 2 computer interfaces, a branch driver and a custom-built interface for an external memory of 64K 16-bit words. The interface consists of 16 separate address and status registers that can operate in read, write or increment mode. Addressing is by word only, so the whole 64K address range is addressable in one

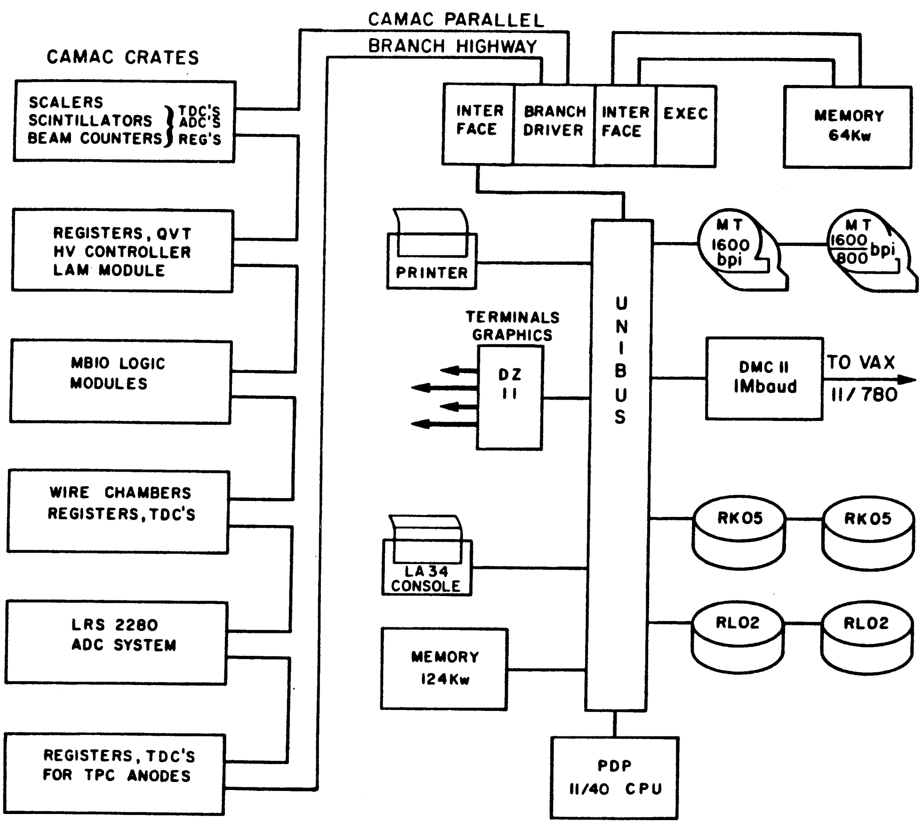

Fig. 2. The TPC data acquisition system.

††MB10/6 programmable logic unit, CAMAC model 202, North Electronic Systems, 17041 Altare, Savona, Italy.

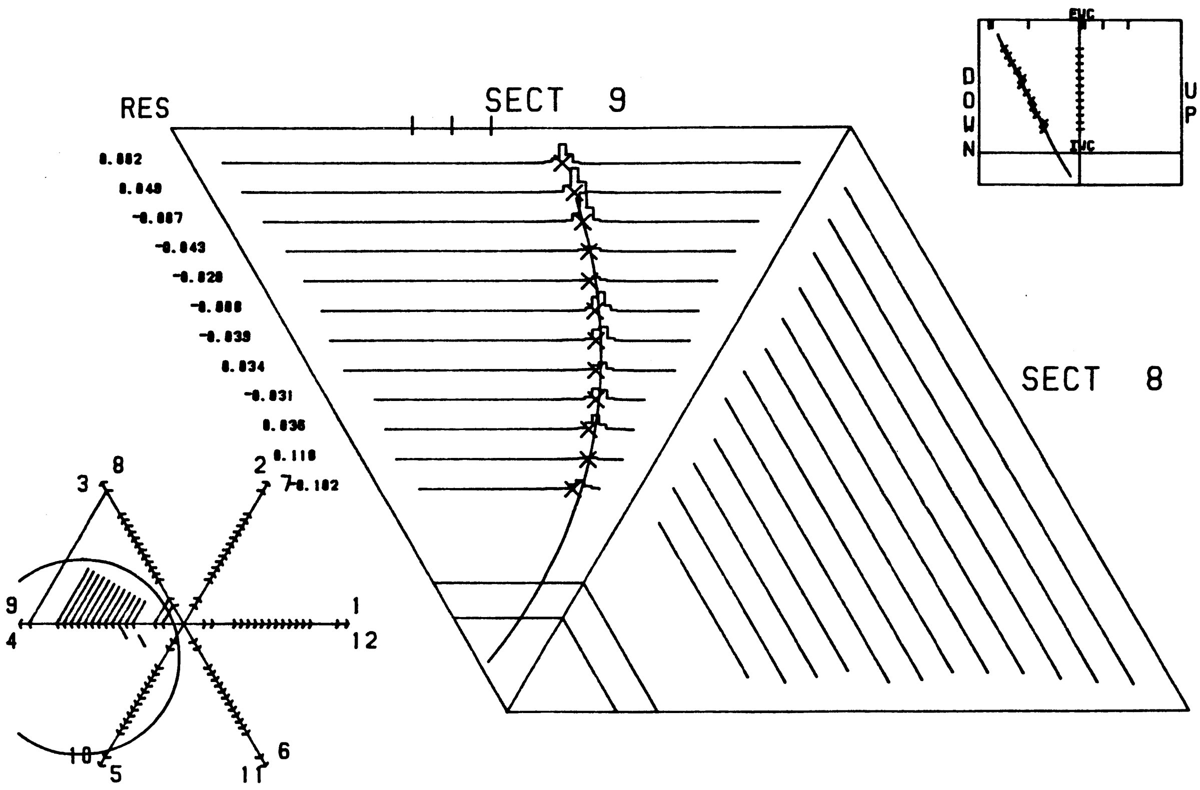

Fig. 3. A photo of a typical event.

Histogramming

Histogramming is done with FIOWA, a TRIUMF supported histogram package. Histograms and scatterplots are defined at the start of the program by a user-written routine DEFINE and are filled after each event by another user-written routine DPLOT.

At the end of the analysis, histograms and scatter plots can be printed immediately or saved on a disk file. This is especially useful when a large number of them (often 100 to 200) are generated. In order to inspect them at a later time, an histogram handling program REPLAY was developed.

REPLAY is now an interactive program that can display, plot or print data as well as perform algebraic operations and do least squares curve-fitting on the data. It can handle all FIOWA type histograms as well as saved files from MULTI, the standard data acquisition package at TRIUMF.[3]

Data input

The same interactive program is now used for on-line and off-line analysis. Data input is based on a subroutine MAGTA capable of retrieving data buffers from a tape, a disk file or a remote computer linked through DECNET.

For on-line operation, the most recently acquired data buffer in the PDP is shipped to the VAX upon request, and then analysed. All histograms and analysis parameters are stored in a shared common and are accessible to other programs. This way, histograms can be displayed and manipulated with REPLAY while data is accumulating. The transfer rate with a DECNET link of 1 Mbd is more than adequate compared to the analysis time.

A general tape handling program called IO and based on subroutine MAGTA is available. It is an interactive program for manipulating data tapes and copying from tape to disk or other tapes regardless of the data format. It is very useful to be able to analyse data from disk when debugging the program, or when the same data has to be analysed many times. Also disk space is now more readily available than tape drives and copying tapes to disk for analysis makes for quicker turn-around time on tape drive usage.

Future Developments

For the future, a plan for demultiplexing the TPC cathode pads or, at least, for giving the TPC multi-track detection capability is under way. Design work to provide the TPC with time-slice read-out is at the prototype stage. The new electronic modules are being designed in the Fastbus technology. In a first stage, pattern recognition will be done with conventional computer software.

Conclusion

The present TPC data acquisition system is capable of handling over 15 events/second. The normal data-taking rate stands at 2 or 3 events/second from a continuous incoming flux of 500 K muons/second. All events are recorded on tape, the hardware is continuously monitored and the dead time is less than 5%.

The PDP-VAX link has proven a great help in setting up and monitoring trigger conditions. It also allows periodic monitoring of the system's efficiency by checking the energy spectra of the calibration reaction.

References

1. D.R. Nygren, spokesman, Proposal for a PEP Facility Based on the Time Projection Chamber, PEP experiment No. 4, SLAC PUB-5012 (1976).
2. C.K. Hargrove et al., Physica Scripta 23, 668 (1981);
M. Blecher et al., Search for Muon-Electron Conversion at TRIUMF, Neutrino-81 Conference, Honolulu, July 1981, TRIUMF report TRI-PP-81-32;
C.K. Hargrove et al., The Spatial Resolution of the Time Projection Chamber at TRIUMF, (submitted to Nucl. Instrum. Methods).
3. T. Miles and A. Satanove, TRIUMF's Data Acquisition System, these proceedings.

16-bit word. Once a register has been set to a particular mode, each data transfer to contiguous memory locations or each memory increment can be done by a single computer instruction. This is very useful for histogramming or block transfers. Since this memory could be accessed by the two computers simultaneously, it served as the means of communication between the two machines.

The PDP 11/40, having no floating point processor capabilities, took the task of reading the events from CAMAC, writing them to magnetic tape, transferring them to the second computer and controlling the experiment. Its configuration is illustrated in Fig. 2. The printer has plotting capabilities and the terminals are VT640's with Retrographics modules. It can acquire data at a rate of 15 events/second.

The Data General NOVA was used to analyse events copied by the PDP to a ring buffer in the external memory. Since it had access to the histograms in CAMAC memory, it was also used for all histogram displays and hardcopy. Crude analysis took about 6 seconds to reconstitute a good track and update histograms. However, any improvement to the program was severely limited by the 32K maximum size of the memory.

Shortly after TRIUMF purchased a VAX 11/780 for data analysis, a 1 Mbd DECNET link was established by means of 2 DMC-11 microprocessor communications interfaces between the PDP and the VAX. Transfer of data buffers was tested between the two machines. Offline analysis was developed on the VAX and could also be used for online sampling. Analysis time was less than 100 μsec/event. Program development on the VAX became common for online and offline work and the NOVA computer was dropped from the data acquisition system to avoid maintaining two completely separate streams of analysis programs and an old machine.

Data-Taking Software

The data-taking software is implemented on the PDP 11/40 under the RSX 11-M V 4.0 operating system. To provide the required speed, all CAMAC operations and histogramming are implemented in a software driver.

The main program called TPC is an interactive command handler written in MACRO. The commands fall in four basic categories :

a) commands to control the data-taking (start, hold, resume or finish run in normal mode or in pedestal measurement mode);

b) commands to set a series of flags, change the hardware conditions or establish a DECNET link;

c) commands to check the status of the experiment,

d) commands to handle the histograms.

Most of these commands are implemented in separate tasks spawned by the main program and they can be run on their own. This makes modification to the code possible while data-taking is on-going.

Here is a description of run processing. When the command RUN is given, the run number is automatically incremented. A run label is written on the magtape and dispatched to the VAX if the link is established. A run sheet is produced containing the answers of the experimenters to specific questions, all hardware settings (magnet high voltage settings, temperature, machine parameters, etc.) and the scaler rates. This runsheet is stored in a disk file and printed. The CAMAC driver is given a buffer address and the order to start data-taking. Every good event produces two interrupts. The first one activates the read-out of all CAMAC modules in a fixed format for which the present size is about 300 words. The second one marks the end of the LeCroy ADC conversion and initiates the read-out of the variable size data, usually 200 to 300 words. Histogramming is performed and the trigger system is enabled.

When the buffer is full, control is returned to the main program that initiates taping of this buffer and dispatching to the VAX if it has requested more data. A new buffer is allocated to the driver.

An end of run can be produced by a user command, a fatal error condition or an end of tape. At this point, two end of files are written on the tape, logging files are updated and an end of run sheet is printed. The logging of statistics and tape contents has been automatized as much as possible because the experiment is expected to produce a few thousand tapes.

The event format has been growing since the start of the experiment. To eliminate the inconvenience of changing the code every time a new module is added, all programs reference a series of pointers written in the tape label and stored in a shared common.

Here is the description of some of the other tasks.

MONIT : this is a monitor program that checks periodically all the scaler rates, the magnet settings, the high voltage levels on the counters, etc. It displays one of 2 pages of information every five seconds and it can stop the run upon detecting a monitored value going out of range.

LOG1 : this program can load the memory of several MB10/6 programmable logic units according to logical conditions set by the user or stored on disk file.

HVO and BHV : these programs control LeCroy and Bertan high voltage power supplies equipped with CAMAC interfaces.

GTPC : this program is an interactive histogram handler that accesses the external memory. It can display, plot or fit the histograms.

Analysis Software

All off-line analysis is performed at the TRIUMF VAX 11/780 data analysis centre. Data is analysed by means of SOFIA, an interactive or batch program made to handle different types (helix or straight line) of TPC data. It performs event by event analysis.

Event analysis

First the ADC data is decoded to find clusters of information called "clumps" corresponding to the induced charges on the discrete pads along each wire. Each clump is fitted by a median technique to find the center of gravity that represents the X position along the wire. Other fits like a gaussian or a line shape were tried. They are time-consuming and do not significantly improve the final results.

Trigger conditions, total charge on each wire and time information are then examined to assign absolute XYZ coordinates to all clumps. A set of points most likely to contain the track is determined by a binning method: a circle passing through the centre of the target is found for every pair of XY points and the circles are binned by location of circle centres. The points in the peak bin are then systematically searched for a track. This search technique has proven much quicker than a method looking through possible sets of points using a random seed. A proper fit is done on the XY and the Z coordinate separately after iterations based on the χ^2 of the fit. All parameters of the track are calculated and histograms are filled. Processing time for a typical event is of the order of 80 μsec.

At this point most of the data relevant to the event can be displayed in a PHOTO (Fig. 3). This routine is interactive and can also display information about every phase of the fitting, and print or refit the track with selected points. Looking at a series of photos online has proven very helpful in checking actual trigger conditions and finding the weaknesses of the fitting techniques.