The TWIST Data Acquisition System at Triumf

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***Abstract*—The TRIUMF Weak Interaction Symmetry Test (TWIST) is an experiment to measure precisely the Michel parameters describing the energy and angular dependence of positrons emitted from the decay of polarized positive muons. The detector consists of a 2 Tesla superconducting solenoid containing 56 planar chambers for high precision tracking of the positrons through readout of some 4200 multihit TDC channels. Being a high precision, high statistics experiment, control and monitoring of the beam and ambient conditions had to be closely integrated into the data acquisition system. A successful data run in 2002 produced more than 6 Giga events expected to yield some first physics results. This paper will describe the details and performance of the DAQ system including slow controls and online monitoring techniques.**

I. Introduction

TWIST (TRIUMF Weak Interaction Symmetry Test) is an experiment designed to measure the parameters describing the energy and angular distributions and correlations of positrons (e^+) from positive muon (μ^+) decay. These parameters are known as the Michel parameters (after Prof. L. Michel [1]). They offer a compact and convenient prediction of the electroweak interaction in muon decay.

The goal of the TWIST measurement is to improve by more than one order of magnitude the uncertainty in the Michel parameters ρ, δ and $P_\mu\xi$ to look for deviations from the Standard Model predictions.

This paper will give a quick overview of the experimental technique before describing in detail the DAQ system and give some performance results.

II. The Experiment

The TWIST experiment [2] uses a highly polarized surface muon beam coming from the decay of positive pions produced by a high intensity proton beam from the TRIUMF cyclotron. The positive muons are transported by a conventional dipole-quadrupole magnetic system (the M13 beamline) to the entrance of a superconducting solenoid, integral component of the TWIST detector (Fig. 1).

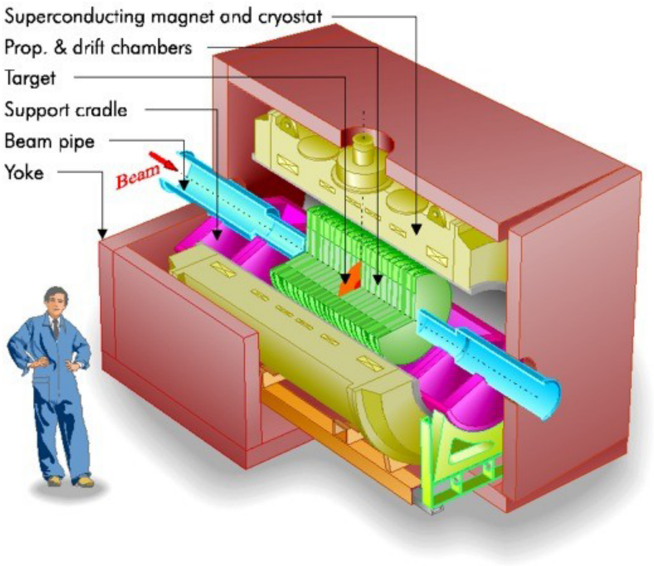

Fig. 1. Cross section of the TWIST detector.

The detection system consists of a stack of low mass planar drift chambers immersed in a uniform 2 Tesla field with a thin target at the center of the stack. The muon decays in the thin target to a positron (e^+) and two neutrinos. The goal of the experiment is to measure with high precision the energy and angle spectrum of the decay positrons.

The detector stack consists of 44 precision planar drift chambers (DC: 80 wires per chamber) filled with DME gas and 12 proportional chambers (PC: 160 wires per chamber) filled with CF_4 isobutane gas. The chambers are organized as U and V planes in modules separated by helium gas. Great care and precision techniques were used to produce a highly symmetric detector around the target plane. An unbiased trigger comes from a signal in a thin scintillator located at the entrance of the magnet. A 10 µs gate opens and all hits on all wires of the chambers are recorded as an event (Fig. 2).

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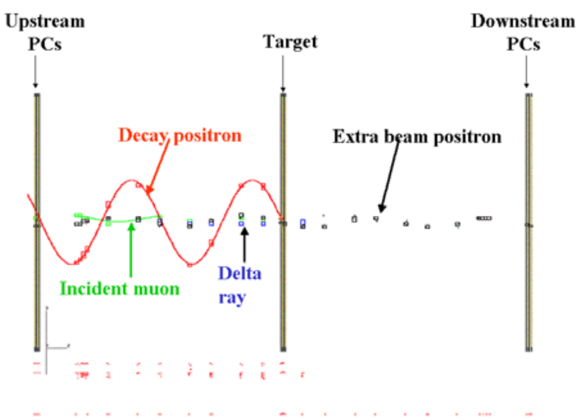

Fig. 2. A complex muon decay event: a muon stops in the target and the decay positron is emitted in the backwards direction. Another positron coming from the beam traverses the complete stack at a later time. The time of the hits are plotted below the event with time increasing in the downward direction.

III. DAQ

The TWIST DAQ system can be divided into two main components: the event-by-event DAQ and the Slow Controls.

A. *Hardware*

All event-by-event DAQ readout modules are LeCroy 1877 Multi-Hit 500 ps TDCs [3]. These modules were chosen because of their short conversion time (10 µs), their zero suppression mode, their internal event pipeline (8 events deep) and their ability to acquire analog information when coupled to LeCroy MQT300a chips. All DCs and the outer eight PCs have only time readout. The signals from the four PCs surrounding the target are split between normal postamplifiers for time readout and special boards with MQT300A chips for analog information. 44 TDC modules are needed to house all 4200 readout channels.

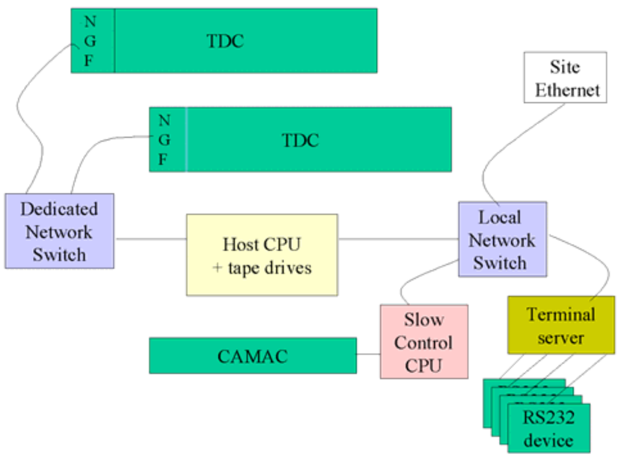

Fig. 3. Main hardware components.

The overall hardware architecture can be seen in Fig. 3. The TDCs are split between two Fastbus crates. Each crate is readout independently by a SIS4100 (NGF) Fastbus to VME Interface [4] driven by a MVME2306 PowerPC (PPC) connected to 100BaseT Ethernet. A dedicated 100BaseT switch connects the two PPC to a dual 1 GHz Pentium Linux host computer with IDE disks and SCSI tape drives. The IDE disks use software RAID to achieve high performance. A second 100BaseT switch connects the host computer to the outside world, to a Slow Controls computer coupled with a CAMAC crate and to several slow control devices connected through Ethernet controllers.

B. *Software*

The software components are built around the MIDAS data acquisition system [5]. It is made up of producer and consumer tasks exchanging data via shared memory buffers (Fig. 4). If a task resides on a remote computer, a handshaking server task on the local computer is automatically started when the remote task makes the initial connection.

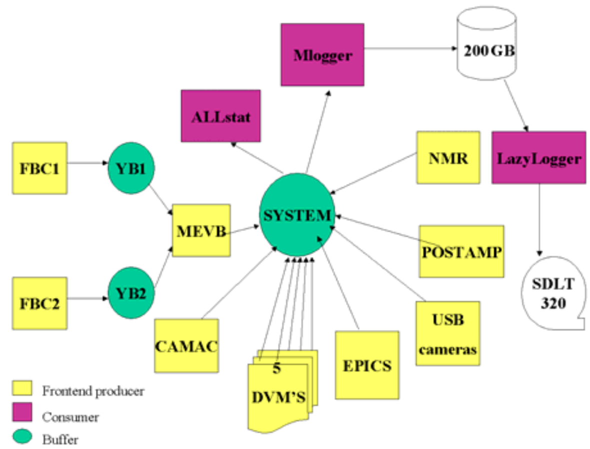

Fig. 4. Main MIDAS software components

Event-by-event data is collected by two front-end producers (FBC1 and FBC2) running on each of the PPC and transferred in parallel to two independent buffers (YB1 and YB2) on the host. An event builder MEVB collects the event fragments from both buffers, combines them and sends the complete events to the main SYSTEM buffer. There are also several slow controls producers sending events to the SYSTEM buffer. The Mlogger consumer requests all events and logs them to disk files. Another consumer, Lazylogger, runs in the background copying data files to tape. Communications between the various tasks is done through the Online Data Base (ODB). This database contains run parameters, logging channel information, condition parameters for front-end producers and event builder, and slow control values as well as status and performance data.

C. *Triggering and synchronization mechanism*

Triggering for TWIST must be sensitive to any muons in the beam without any bias. A very thin scintillator with a threshold set to select muons is used. The trigger signal generates the TDC stop after a 10 µs delay. It is also fed to one TDC channel in each crate to determine accurately the trigger time since there is a significant jitter on the "stop" signal, caused by ambient temperature changes. It has been observed to be ~8 ns for a 5°C difference between night and day.

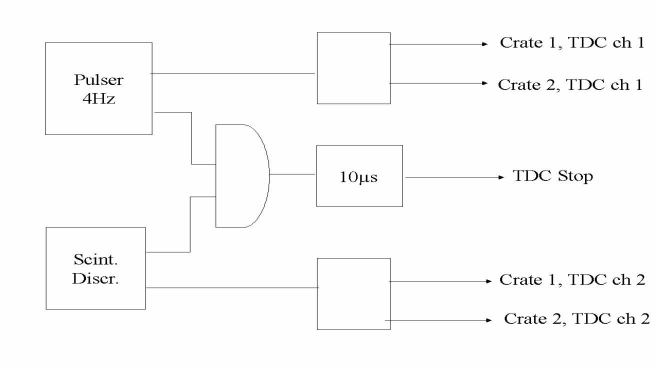

Fig. 5. Trigger and event synchronization mechanism

As can be seen in Fig. 5, the TDC stop is fed simultaneously to both Fastbus crates. Since each crate has it's own independent frontend producer, there is a need for a synchronization mechanism between the two crates. This is done by inserting "blank" synchronization events triggered by a pulser operated at 4 Hz. This signal is also fed into a TDC channel in each Fastbus crate to tag these synchronization events. The software event builder on the host computer checks each event fragment. If it finds a "blank" event tag, it makes sure that this tag is present in each fragment of the event. Otherwise it stops the run. A further test is done in the online monitoring, checking for absence of wire chamber data at the time of the "blank" triggers. Synchronization errors occur less than once a week.

D. Web access

TWIST makes extensive use of the MIDAS web server for:

- run control and status page (see Fig. 6);
- history plots of all the slow controls variables with query mechanism (see Fig. 8);
- electronic logbook (ELOG) with attachments and access to details of all runs;
- error messages.

The web server can be accessed from any web browser. It uses different passwords for read and write access. The collaboration has found the web access extremely useful to keep track of ELOG entries and status of the system. It makes it also very easy for experts to check the system from home.

There is also a web interface to an SQL database describing data tape contents. That database is filled automatically by the DAQ system.

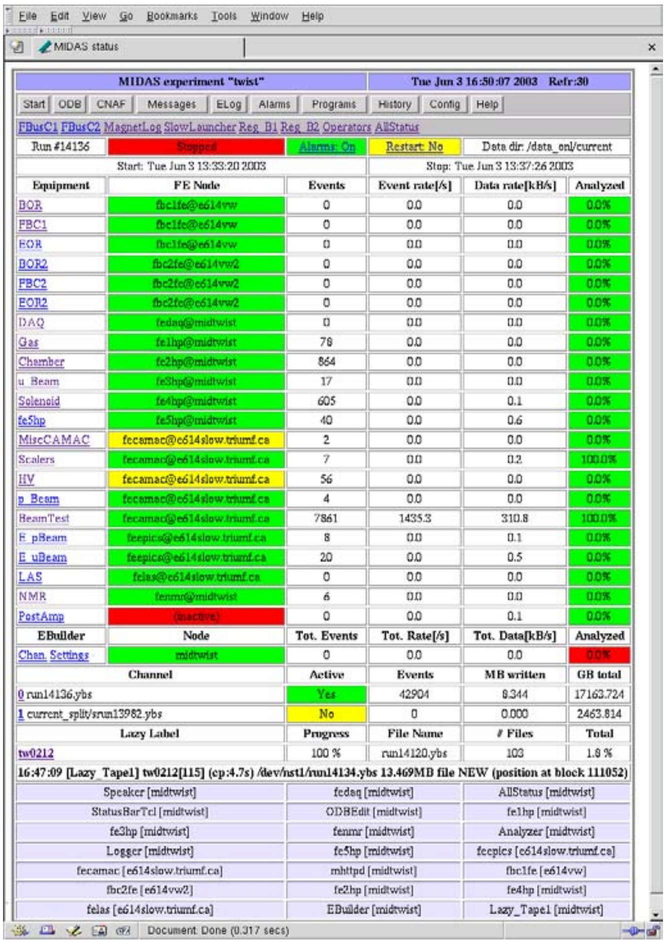

Fig. 6. Run control page as seen from a web browser

IV. Slow Controls

The Slow Control system consists of a number of frontend tasks, each interfacing to different hardware:

- A CAMAC interface to SADC/DAC modules for high voltage control and monitoring and for control of a gas degrader for changing the beam momentum, to a reflective memory containing parameters from the primary proton beam control system, and to scalers;
- RS-232 interfaces to five Agilent/HP Digital Voltmeters (DVM) monitoring the gas system, temperatures at 80 locations in the detector stack, conditions in the solenoid magnet, in the readout crates and in every element of the secondary beamline;
- USB interfaces to five CCD cameras for monitoring the position of the chamber stack in the solenoid magnet;
- RS232 interface to the NMR probes in the bending magnets and the main detector solenoid;
- Interface to the Epics system controlling the secondary muon beamline for monitoring the settings and for regulating the beamline by applying fine tuning corrections on the bending magnets;
- RS232 interfaces to a custom system of 290 postamplifier boards for setting thresholds and test pulse levels on the chamber electronics as well as monitoring voltages and temperatures on the boards.

The RS232 interfaces are handled by Emulex 4000 terminal servers and by Belkin USB to serial adapters.

Overall there are some 2500 channels of slow control data, recorded every minute in the history files and sent to the data stream at the beginning of each run. If any value changes by more than a set threshold, the new values are sent as events to the SYSTEM buffer.

Fig. 7. The Global Status Bar, colors on the buttons indicate the status of the subsystem.: gray=inactive; white=active, not enabled; green=active, enabled; yellow=active, enabled, warning; red=active, enabled, error

The frontend task called AllStat checks the status of all other tasks. A single Tcl window called the Status Bar (see Fig. 7) presents the global status of the complete experiment to the operator with warning/error conditions presented as different colors of the buttons on the status bar. A single mouse click provides access to a hierarchical system which allows the operator to pinpoint the exact cause of the alarm.

In addition, easy access is provided to the history of any slow control variable monitored by the system. Fig. 8 is an example of a history plot.

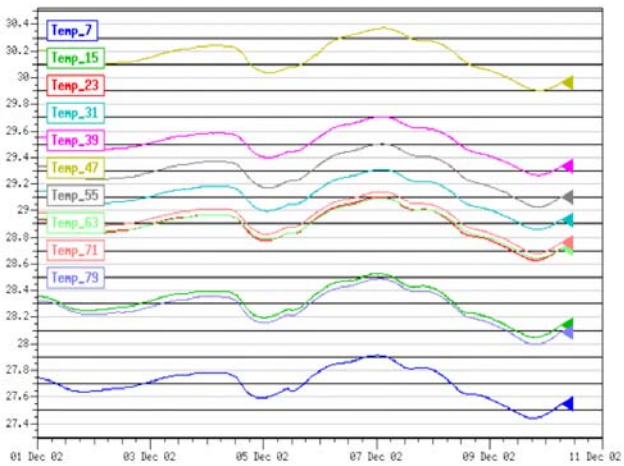

Fig. 8. A history plot of temperatures at various positions in the detector stack

The system also makes use of the MIDAS alarm system where different classes of alarms can be set. There is visual notification of occurrences of errors as well as audio messages generated through the Festival Speech Synthesis System [6].

V. Online Monitoring

In such a precision experiment as TWIST, online monitoring is extremely important to spot any change in the running conditions.

A. QOD: Quality Of Data

The offline analysis code without tracking is used to monitor the data quality. One million events are analyzed every hour checking wire multiplicities, wire occupancies, drift times, event length distributions, TDC error codes and crosstalk rates. Automatic comparisons using the Kolmogorov test (modified version of the HBOOK hdiff mechanism [7]) to a reference histogram set are used to flag suspicious changes.

B. Sample File Analysis

A set of files containing a sample of the events is written in parallel to the main data stream. These files are submitted automatically for full analysis including tracking. The output histograms are kept for comparison with a standard set of histograms. With a sampling rate of 1% of the events, the analysis can keep up with data production and the files can all be kept on disk for the length of the data taking period (~100 GB over a 3 month period) for fast reference.

C. Full Run Analysis

Since some problems can only be seen with histograms containing high statistics, one full run (2 GB) is also analysed completely in parallel.

All these procedures are automated via a custom designed queuing system. Every run is queued for analysis of all of the three types A-C as soon as it is finished. For each of the A-C queues there is one or several analysis tasks running on several hosts of the local network. Each queue is a LIFO, so that the shift crew always can look at the most recent data. How much data actually gets analyzed depends on the number of CPUs assigned to a queue, and can easily be adjusted.

VI. Performance and Status

Originally, TWIST used a DLT8000 tape drive for data logging. It became the bottleneck for logging at > 6 MB/s. Adding a second drive increased the throughput but made it more complicated to retrieve data runs. In August 2002, a SuperDLT 320 was substituted for the two DLT8000. Transfer rates to the tape in excess of 15MB/s are now achieved routinely. There are also significant savings on tape costs due to the higher capacity of the SuperDLT cartridges.

Overall, the TWIST DAQ system is capable of sustaining a trigger rate of 5000 events/s with event size of 1500 B for an overall throughput of 8MB/s. When running at maximum speed, the event builder MEVB uses the most CPU time (~35% of a 1GHz Pentium III). The other CPU hungry tasks are the Mlogger and the two servers receiving data from the two PPCs (each uses ~ 30% of the second CPU).

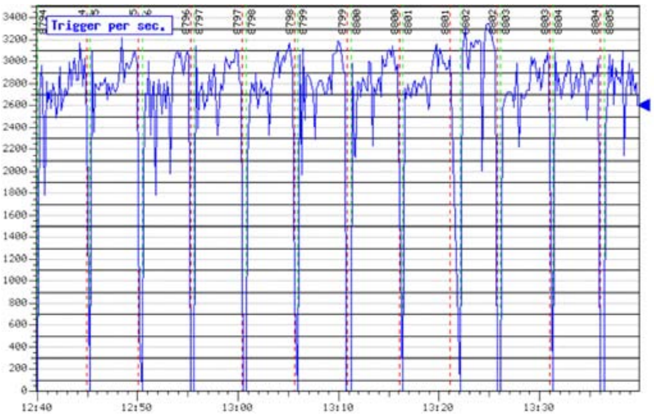

Fig. 9. Typical trigger rate displayed by the Midas history tool

The system has been used for the first physics run from August to December 2002. Fig. 9 represents a typical data taking situation where the trigger rate was set to 3000 triggers/s for physics reasons. The system was set to automatically restart the runs to limit the output file size to 2 GB.

At this stage of the Twist experiment, where we are attempting to determine two of the Michel parameters, ρ and δ, with a precision of better than one part in 10^3, some $3x10^8$ events are sufficient to constitute a statistically significant data set. During the fall 2002 run, approximately 6 $x10^9$ events were collected in order to measure quantitatively the effects of variations of experimental conditions.

Hardware and software were very reliable and contributed less than 1% to downtime.

At present, analysis of the 2002 data is proceeding with a result expected in early 2004. Meanwhile improvements to the muon beam and to its characterization are under way to enable Twist to measure the next Michel parameter $P_\mu\xi$ to a precision of one part in 10^3.

VII. Acknowledgment

The authors would like to thank Grant Sheffer and Brian Evans for their role in providing hardware for the DAQ and slow controls.

VIII. References

[1] L. Michel, *Proc. Phys Soc*, vol A63, p 514, 1950
[2] N.L. Rodning et all, "TWIST – The TRIUMF weak interaction symmetry test: the Michel parameters for mu+ decay," *Nucl. Phys. Proc. Supp.* , vol. 98, pp. 247-254, 2001
[3] LeCroy Research Systems, Chestnut Ridge, NY: http://www.lecroy.com/lrs/
[4] SIS GmbH, Hamburg, Germany: http://www.struck.de
[5] S. Ritt and P. Amaudruz, "The MIDAS DAQ system", *Proc. of the X^{th} IEEE REAL TIME Conference,* Beaune 97, pp 309-312. : http://midas.triumf.ca
[6] The Festival Speech Synthesis System, University of Edinburgh, http://www.cstr.ed.ac.uk/projects/festival
[7] HBOOK package from CERNLIB, CERN Program library,: http://wwwasd.web.cern.ch/wwwasd/index.html