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DIR-6-86

DEMON, TRICAL AND DECAL: THE SPS ONBOARD ANALYSIS PROGRAMS

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INTRODUCTION

Three programs have been developed for data analysis to be performed at sea during the SPS cruise. **DEMON** takes the data in the event buffer, assumes they are from muons, and converts it to arrival times and PMT charges, displaying the results on the terminal so the user may monitor SPS operation. It then attempts to reconstruct the muon's direction, presenting results event-by-event and in summary, with histograms, at any stage.

TRICAL sends triggering commands over the low speed data link to the Calibration Modules (CM) under user control. **DECAL** can spawn TRICAL as a separate task and then analyzes the data in the event buffer which has been shipped up from the optical modules (OM) and CM over the fast (F/O) data link. The OM and CM data are read and checked, and the OM data are processed to check relative timing and whether the measured PMT charges agree with what is expected, assuming a nominal water attenuation length. An event-by-event fit is then performed on the data from all PMT's to determine the best value of the water attenuation length. Histograms of the individual PMT and CM photodiode charges and arrival times, the fitted attenuation length and fit error can be examined at any time in the event sequence.

A fourth program, **TRISP**, allows the user to type in the ranges read off the TRISPONDER receiver and calculate the ship's coordinates. TRISP is not described in this report.

PROGRAM STRUCTURE AND OPERATION

I will not present here the details of the menu-driven operation of the programs. These are best seen by sitting down at the terminal and running through them yourself. Below I describe the structure and operation in terms of the subroutine calls. This description is designed to help the user follow the program logic when he examines the actual source listings. These are extensively commented.

Except for system files, the files for TRICAL, DECAL, DEMON and TRISP are on DL1:[20,20]. This can be accessed by logging on under STENGER, Password NOSMOK, or under the system manager username WILSON. (There are certain system commands, such as INSTALL, which are privileged to the system manager.) To see the names of the source files, how to compile and link them, list DOALL.CMD, which is used to make up everything from scratch.]

Because of computer limitations, a multiple-task operation is used in which different tasks are "spawned" during program operation. Spawning is done by calling an SPS system routine {SPNWAT}, so logically it is like a subroutine call. However the spawned program is actually a separately executable program with a "STOP" in the place of the conventional subroutine "RETURN." Here data are transferred between tasks by storing them in a special common /DECOMM/ which occupies a specific place in memory. Almost all the variables, constants and parameters needed by more than one routine are stored in /DECOMM/. In order to make all this work, you must link using the command file VIC.CMD (see file DOALL.CMD).

In the following, subroutines which are common to several programs are enclosed in square brackets: [subroutine]. SPS system routines (written by C. Wilson or G. Sembroski) and enclosed in curly brackets: {subroutine}. A large number of display and other utility routines which are called, most developed by C. Wilson and used elsewhere in the SPS system, are not specifically mentioned.

DEMON

DEMON is broken into two tasks. After optionally reading OM or Monte Carlo data from disk in an offline mode or from the SPS data buffer in online mode, DEMON spawns task MUFIT to process the data. The functions and calling sequences of DEMON are briefly described below.

DEMON
Main calling program. Asks user for options and steers analysis.

[DEFY] (entry point in [DEFILE])
Opens input data file in offline mode.

ISPOOF
Initializes for data analysis.

[SETCON]
Sets constants (such as π) and puts in /DECOMM/.

Reads a line of control data stored on file SPF.INP:

MAXEV = maximum no. of events to process
MINDET = minimum no. of OMs to use in muon fit
LEVPRT = a print level indicator
MPRT = max. no. of events to print
IOPT = 0 to include PMT charge in muon fit, 1 for time only
MODE = 0 normally, = 1 + no. of noise pulses to be inserted in Monte carlo data.
CHICUT = maximum χ^2 for acceptable muon fit
GATE = width of software gate (in 5 ns units) applied to raw arrival times relative to trigger.

[IHIST] (entry point in [HIST])
Initializes histograms.

[EVENT]
Obtains the event data in online mode.

{GETEVT}
Gets data from CAMAC and puts it in data buffer /DBUFF/.

[DEFILE]
Obtains the data in offline mode. In this case, the data are assumed already to be formatted as is online data by [EVRDY] below. It can be real data or Monte Carlo. This option could be used for offline analysis when program is transferred to VAX, with a pre-processing program reading the actual raw data tapes, making various checks and selections, and writing a disk file in this format for further analysis by the same routines, modified and expanded to perform the more detailed analysis which would be done at that stage.

[EVRDY]
In online mode, takes the data in data buffer and formats it for further processing. The formated words are put in /DECOMM/. In either offline or online mode, spawns task MUFIT for muon events and task CALB for calibration analysis.

MUFIT
This is the task which calls SPOOF to perform muon analysis.

SPOOF
Steers the muon analysis.

[SETUP]
Takes the data formated above (either from [DEFILE] or [EVRDY]) and converts it to photoelectrons and nanoseconds.

Function [QCAL]
Returns photoelectrons (Q) for input of pulse width (PW). Uses calibration of S. Matsuno DIR-1-86: Q = 10**(PW - PWZ)/PWB. See SETCON for the constants PWZ and PWB for each PMT. Typical values are PWZ = 100 ns and PWB = 350 ns.

Function [QERROR]
Returns error in Q, δQ = 230.3*Q/PWB, which assumes a 100 ns error in pulse width (see DIR-1-86 and Fig. 1c). Typically, $\delta Q/Q = 0.7$.

Function [TCAL]
Returns calibrated time of arrival of pulse at PMT in ns: TCAL = 5*ITIM + TFD - TPD; where ITIM is arrival time in 5 ns units; TFD is the fiber delay for the particular OM and TPD is a PMT charge-dependent correction: TPD = 41.4-10.1*(PW - PWZ)/PWB; if TPD < 0, set = 0 (see SETCON, and DIR-1-86; note that the older

parameterization shown in Fig. 1a is obsolete).

Function [TERROR]
Returns error in time in ns.
TERROR = 3 ns for PW $<$ 430 ns
TERROR = 15 - 0.028*(PW/ns) for PW $>$ 430 ns
(see Fig. 1b).

STRIFE
Reconstructs muon direction. This routine and its subroutines were lifted from the DUMAND Monte Carlo program, DUMC. The Appendix gives the details of the reconstruction and equations, as they were originally used in DUMC. Some modifications have been made since that was done: (1) the errors in t and q are as described above; (2) the χ^2 now includes un-hit PMT's.

MINER
χ^2 minimization routine (from HEPG VAX library)

STRISQ
Computes χ^2 for muon fit.

[HIST]
This is called for each histogram and each event to increment the histogram bin. Similar to HFILL in HBOOK.

[POOF]
Prints data analysis summary.

[PHIST] (entry of [HIST])
Prints histograms (on screen)

TRICAL

TRICAL can be run separately, however in normal operation it is expected to be spawned by DECAL under user control. TRICAL first calls subroutine ICALT which initializes the job and prompts the user for the various options. Either module may be triggered in one of two modes:

MANUAL. One trigger pulse with step-filter attenuations:

x	0	4	1	5
Atten.	1	1/2	1/4	1/8

where x is the last digit in the commands described below.

AUTO. 32 triggers in 4 sets of 8 pulses each at various step-filter settings according to the following 9 options:

x	Attenuations			
A	1	1/2	1/4	1/8
8	1	1/2	1	1/2
2	1	1	1/4	1/4
9	1/4	1/8	1/4	1/8
6	1/2	1/2	1/8	1/8
0	All 32 pulses at 1			
4	All 32 pulses at 1/2			
1	All 32 pulses at 1/4			
5	All 32 pulses at 1/8			

The actual triggering is done by subroutine CALTRG which calls the SPS system routine {COMFIL} that actually sends the commands along the low speed link. Another system routine {WTSCND} is used to provide the needed delays between various commands.

In MANUAL mode the first command ($nnWF2x) turns off the charger of module n, switches power to the laser and sets the attenuator. After a 7 sec. warmup, the trigger command ($nnWF2x)is sent. Then a third command ($nnWF0x) turns the laser off and the charger back on. A wait of 90 sec. is then instituted to allow the battery to re-charge before the next trigger.

In AUTO mode only two commands are sent: a reset ($nnWFCA) which disconnects the charger and turns on the laser and, again after 7 sec., and a trigger ($nnWF4x) which initiates the desired sequence. The charger is re-connected automatically after the completion of the sequence.

For other details on triggering the CM, see notes by M. Webster (July 20, 1986) and J. Learned (Dec. 1, 1986).

DECAL

DECAL is broken into three tasks: task TRICAL, as described above, and task CALB. After triggering the CM, or optionally reading CM or Monte Carlo data from disk, DECAL spawns task CALB. The functions and calling sequences of DECAL are briefly described below. Subroutines enclosed in brackets, [subroutine] or {subroutine}, are used also by DEMON and are described above.

DECAL
Main calling program. Asks user for options.

Task TRICAL
See above.

[DEFY] (entry point in [DEFILE])

ICALM

Initializes for calibration analysis.

[SETCON]

ICALM Reads a line of control data stored on file CAL.INP:

MAXEV = maximum no. of events to process
MINDET = minimum no. of OMs to use in analysis
LEVPRT = a print level indicator
MPRT = max. no. of events to print
IOPT = atten. fit option: 0 unormalized, 1 normalized to CM (see discussion under "STATUS" below).
MODE = 0 normally, = 1 + no. of noise pulses to be inserted in Monte carlo data.
CHICUT not current implemented. Could be cut used to discard certain PMT hits from analysis.
GATE = width of software gate (in 5 ns units) applied to arrival times relative to trigger.

[IHIST] (entry point in [HIST])

[EVENT]

{GETEVT}

[DEFILE]

[EVRDY]

CALB
This is the task which calls CALM to perform calibration analysis.

CALM
Steers the calibration analysis.

[SETUP]

Function [QCAL]

Function [QERROR]

Function [TCAL]

Function [TERROR]

CALEX
Computes expected PMT arrival times and charges for calibration events for a nominal attenuation length at the CM scintillator wavelength ATLNOM, currently 25 m, set in SETCOM. The equations programmed can be found in VJS report, DIR-5-86.

[HIST]

LATTEN
Does a fit to the PMT charge data to determine the attenuation length of water at the CM scintillator wavelength. For details, see DIR-5-86.

PALM
Prints calibration summary.

[PHIST] (entry of [HIST])

STATUS

The programs have been extensively checked using Monte Carlo data input. In addition, DEMON has been successfully run on simulated OM data using the "optical octopus" to feed signals to the SBC where they were processed and shipped along the cable to the computer. Actual muon fits, which correctly gave horizontal tracks, were obtained. This was undoubtedly the most significant system test to-date. Since the OM-SBC link has already been extensively tested, we have every expectation now that these parts of the system will work.

There is considerable testing still to be done on the calibration system, which is more complicated in many ways than actual data taking. TRICAL needs to be run with the CM's in the string, to test their control. The data from the photodiode in the CM needs to be read by DECAL. Also, the photodiode must be calibrated at some level and these calibrations entered into SETCON. Currently only nominal calibration constants are used. Thus the attenuation fit option (IOPT = 1) in which PMT outputs are normalized to the CM photodiode will not give the correct results in the current version.

It also remains to be determined how the actual calibrations will be performed at sea. As described above, DECAL can be used to trigger the CM's by spawning TRICAL. In that case, the data in the event buffer should be from calibration pulses. DECAL assumes step attenuator values in doing the un-normalized attenuation fit (IOPT = 0). A more complicated scheme in which TRICAL is spawned on a regular basis during regular data-taking (by OPR?) and the data in the buffer sorted out between calibration pulses and muons has not yet been implemented. The spawning of TRICAL is trivial, but the sorting-out may not be. When there is no step attenuator setting found in /DECOMM/, DECAL will ask for the user to provide one. Thus it is possible to figure out what the attenuator settings are by looking at a series of CM photodiode outputs, and then inserting these manually for the attenuation fit. Of course, it is better if this can be done automatically.

HISTOGRAMS IN DEMON AND DECAL

Because of practical problems which can be solved with more time, the histograms in DEMON and DECAL are not currently displayed with descriptive labels. Thus the user must rely one the histogram number to know what is being plotted. Here are the histograms currently implemented:

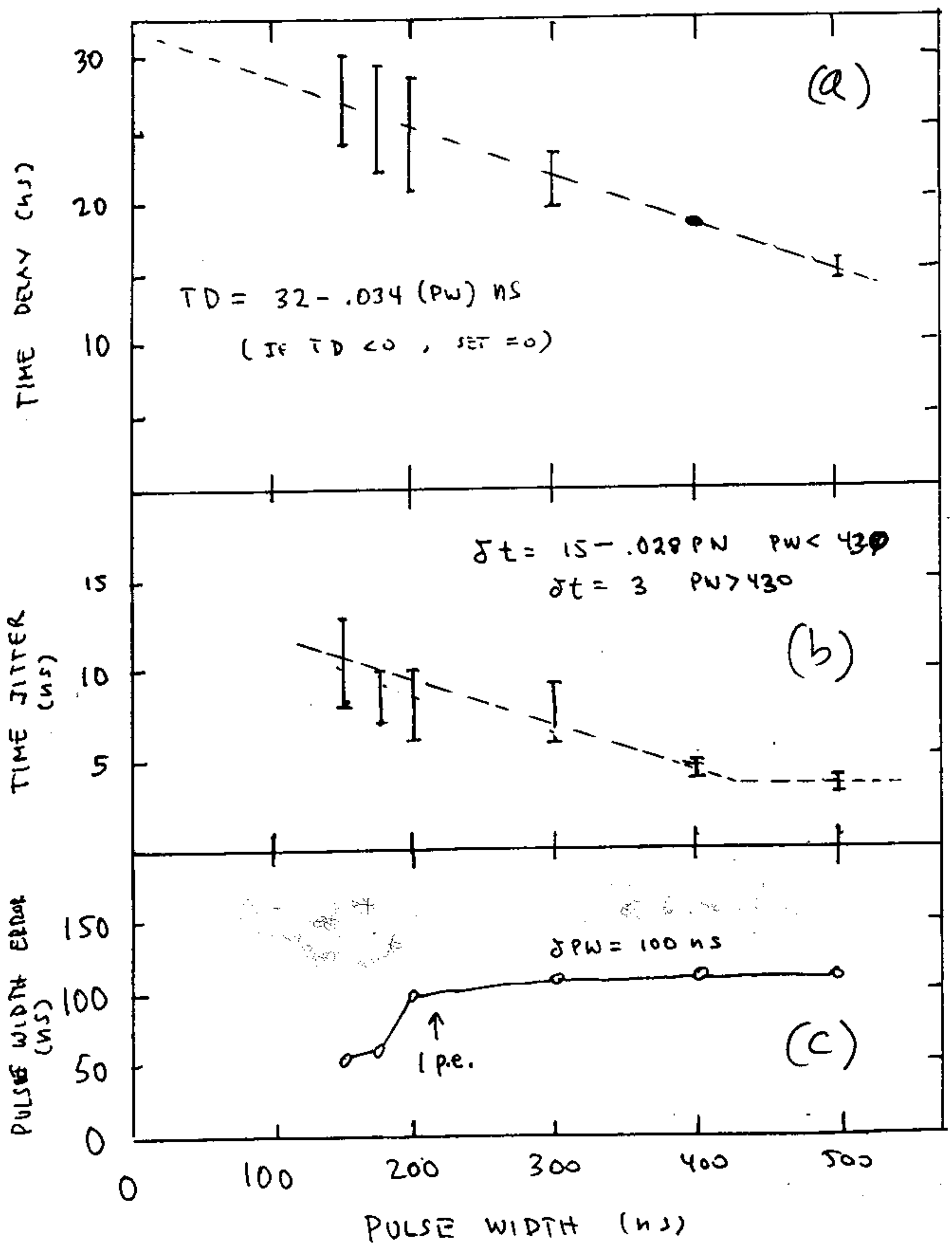
DEMON

Histogram No.	Contents
1.	cosine of muon zenith angle

DECAL

Histogram No.	Contents
1-9	Measured arrival time of signal in detectors 1-9, in ns, minus the expected arrival time for calibration pulse. Use to check and fine tune the delay constants in SETCON. Detectors 8 and 9 are CM photodiodes.
10-18	Measured charge in detectors 1-9, minus the expected charge for calibration pulse.
19	Fitted attenuation length, in m
20	Fractional error in fitted attenuation

Fig. 1 shows a typical PMT time delay (a), time jitter (b) and pulse width error (c) as a function of pulse width, using results of S. Matsuno from a report dated April 24, 1986. The time delay (a) is now parameterized as given in the text from DIR-1-98. The time jitter (b) is used for the time error in subroutine TERROR. The pulse width error (c) of 100 ns is used to calculate the error in PMT charge in subroutine QERR.



APPENDIX

Single Muon Track Reconstruction

Refer to the figure. Given a set of detectors at positions $\{(x_i, y_i, z_i), i = 1, N\}$. At time zero on the experimenter's clock, a muon with an *unknown* direction (θ, ϕ) passes through an *unknown* position (x_o, y_o, z_o). The experimenter has a set of numbers $\{(x_i, y_i, z_i, t_i, n_i)\ i = 1, N\}$, where t_i is the measured time of arrival of the signal at PMT i and n_i is the measured number of photoelectrons (i.e., charge) $\equiv q_i$ of the signal. From these numbers he wishes to determine as much about the muon as possible; ideally, $x_o, y_o, z_o, \theta, \phi, E_\mu$. This is possible with an *array* of detectors. For a single vertical *string* of detectors there is an azimuthal symmetry which makes ϕ undefined. All one can determine is that the muon is on the surface of a cone of half angle θ.

In principle, then, we can determine the following quantities:

- The angle θ, which will be the zenith angle to the extent that the string is vertical.
- The distance of closest approach of the muon to the string, or *impact parameter*, b.
- The z-coordinate (along string) of the point of closest approach, z_b.
- The time of flight of the muon from (x_o, y_o, z_o) to the point of closes approach, t_b.

For a given set of values of these four parameters and the z-coordinate of the detector, one can calculate the *expected* values for the arrival time and charge of the pulse at each detector: $\check{t}_i(b, \theta, z_b, t_b, z_i)$, $\check{n}_i(b, \theta, z_b, t_b, z_i)$.

Given the measured values n_i and t_i at each PMT one can form

NOTE: zero hits are included in χ^2

$$\chi^2 = \sum_{i=1}^{N} \left[\frac{(t_i - \check{t}_i)^2}{\delta t_i^2} + \frac{(n_i - \check{n}_i)^2}{\sout{(\check{n}_i + 1)}\ \delta q_i^2} \right] \qquad (1)$$

which can be minimized to determine the best values of the parameters. In (1), δt_i is the time resolution of detector i, which could be adjusted based on the value of n_i, and the error in n_i is taken to be ~~$\sqrt{\check{n}_i + 1}$~~. Other types of weighting in the χ^2 can certainly be used. see FUNCTION QERR

Because of backgrounds, only those detectors with n_i greater than some threshold yield measured values for t_i and n_i. However, the *predicted* values for these quantities can still be calculated and the χ^2 expanded to include terms like the second half of (1) with $n_i = 0$.

The Equations

The equations needed for the above analysis were first worked out by J. Learned and then put in slightly different form by V. Stenger. A copy of the detailed derivations is available on request. The results will only be listed here.

The predicted time for the hit at detector i is given by

$$\check{ct_i} = ct_b + (z_i - z_b)\cos\theta + \tan\theta_c[b^2 + (z_i - z_b)^2 \sin^2\theta]^{\frac{1}{2}} \tag{2}$$

where θ_c is the Čerenkov angle in water.

The expected number of photoelectrons will depend on the perpendicular distance of the track to the detector

$$d_i = [b^2 + (z_i - z_b)^2 \sin^2\theta]^{\frac{1}{2}}. \tag{3}$$

A subroutine called PHOMIZ written by J. Learned (DUMAND Internal Report 81-10) can be used to compute the number of photoelectrons expected from a minimum ionizing track at a distance d_i for a wide choice of water clarities. Effects such as the spectral transmission through the PMT enclosure are included.

The above, plus a minimizer, are all that are needed to reconstruct tracks for a string of phototubes. The codes have existed for sometime in the DUMAND Monte Carlo program DUMC and in the Muon String reconstuction programs. In order to use with a Monte Carlo, another set of equations is needed, viz., those which give the *true* values for the four parameters in terms of the known position and direction of the simulated track.

Given the true track position at $t = 0$, (x_o, y_o, z_o), and its zenith and azimuth, (θ, ϕ), we have

$$b = (x_o - x_i) sin\phi - (y_o - y_i)\cos\phi \tag{4}$$

$$z_b = z_o - \cot\theta[(x_o - x_i)\cos\phi + (y_o - y_i)\sin\phi] \tag{5}$$

$$ct_b = (z_b - z_o)\sec\theta. \tag{6}$$

Fig. A1. Definition of the parameters used in SPS muon reconstruction.