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THE MICROPROGRAMMABLE PROCESSOR ESOP IN A SMALL ANGLE ELASTIC SCATTERING EXPERIMENT

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ABSTRACT

The microprogrammable processor ESOP has been introduced in the trigger system of a small angle elastic scattering experiment on a polarized proton beam at the Saturne synchrotron. ~~We describe~~ its implementation in a data acquisition system based on a Hewlett-Packard computer/ and we present some preliminary results on the performance of a straight tracks rejecting algorithm [illegible]

[illegible]

1. INTRODUCTION

As a part of the 'Nucleon-Nucleon' program [1] at the Laboratoire Nationale Saturne, Saclay, our group is studying the elastic scattering on protons of the polarised protons accelerated by the Saturne synchrotron, in the small scattering angle region of Coulomb-Nuclear interference [2].

The ESOP processor application described here is part of the trigger system of the detector built for this experiment; we consider it as a first approach which will be developed in future double-scattering experiments [3] and in high-energy polarimetry [4].

2. HARDWARE

2.1 THE DETECTOR

The set-up, at present on the floor at Saturne, is sketched in fig.1. A similar apparatus has been previously tested at the CERN PS : a complete description of the experimental method can be found in reference [5].

Two telescopes of proportional chambers (PC1-PC3 and PC4-PC6) measure the directions of the incoming and scattered protons respectively. Each module PC_i samples the charged particles tracks in the x and y projections with 1 mm (PC1-PC4) or 2 mm (PC5,PC6) pitch.

The target [5] is segmented in thin slabs (T1-T12) of scintillating material [1] and we search for scattering events on its free hydrogen [2] . A photomultiplier is coupled to each T_i and collects the light produced by the slow recoiling proton (kinetic energy lower than 10 Mev) stopping inside the scintillator ; an ADC measures the delivered charge, which is a function of the recoil energy. The thickness (a) and separation (b) of the target counters T_i have been chosen in order to optimise (a) the (scattered + recoil) energy deposition with respect to the minimum ionisation of the direct non-interacting particles and (b) the association of the reconstructed interaction vertex with the target counter giving a recoil signal.

Beam-defining counters (F1-F4) and angular acceptance limiting counters (L,S,F7) complete the apparatus.

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[1] NE102, approximate chemical composition : CH ; thickness : T1-T4 0.5 mm, T5-T9 1 mm, T10-T12 2 mm.

[2] Density : 0.08 g/cm^3.

The correlation between scattering angle and recoil energy allows a good separation of the elastic signal from the pp inelastic and the Carbon induced backgrounds (fig.2): the feasibility of the method has been demonstrated in the tests at CERN [5] and in preliminary data taking runs at Saclay.

2.2 THE TRIGGER

A first level counter trigger is given by a coincidence of the following conditions :

1. a beam particle ($F1 \cdot F4 \cdot (\overline{F3+F2})$) ;
2. a scattered particle ($S \cdot L$) with partial suppression of the direct beam ($\overline{F7}$) ;
3. one and only one target counter above a threshold discriminating recoil protons from single direct particles.

A further selection level is needed to improve the direct beam suppression. Indeed, the cut in scattering angle:

1. must be as sharp as possible, since the elastic pp cross section angular dependence has a large slope in the Coulomb-Nuclear interference region;
2. must be independent of the position of the interaction vertex along the beam line (i.e. of the target T_i in which the interaction occurs) and of the beam characteristics (spot and divergence), expected to vary with the energy of the beam.

Geometrical cuts provided by anticoincidence counters at fixed positions are clearly inadequate for these purposes; moreover, in case of misalignements with the effective beam axis, such cuts introduce instrumental asymmetries, i.e. possible sources of systematic errors in polarization measurements.

A fast processor capable of selecting events on the basis of the calculation of the scattering angle from the coordinates provided by the proportional chambers is the answer to these problems.

2.3 THE MWPC READ-OUT SYSTEM AND THE PROCESSOR

The proportional chamber read-out system we adopted is the RMH system [6], a CERN standard characterized by high speed ECL 10K technology and by the capability of non-destructive read-out for data pre-processing. Dead times are minimised by the choice of cables as delay elements and the data transfer rate in optimal conditions can be as fast as about one 16-bit word/100 nsec, each corresponding to an encoded proportional chamber wire hit.

ESOP is a CERN-built microprogrammable processor, operating on 16-bit data words ; data and instructions occupy separate memories,and three independent ALUs perform in parallel operations on data, data memory addresses and instruction memory addresses. The basic cycle time is 125 nsec. A fast 16x16-bits multiplier with accumulator and a special shift unit enhance the computing power of the processor. In our configuration 4096 words of data memory and 1024 words of 48-bit instruction memory are available. CAMAC interfaces give access to ESOP memories and registers. An interface connects the RMH system directly to one of the three independent I/O ports of the data buffer memory.

Detailed descriptions of the ESOP hardware can be found in reference [7].

3. SOFTWARE

Our software work included (a) adapting the standard utility programs to our HP (only NORD and PDP versions were supported by CERN), developing additional debugging tools (b) and on-line data filtering algorithms (c).

3.1 GENERAL UTILITY PROGRAMS

ESOP can only be programmed in machine language, with the help of a cross-assembler running on an external computer.

Since the early stage of the project we have been using for source file editing and maintenance the CERN IBM Wylbur system ; an IBM version of the cross-assembler produces object files which can be transported to our on-line HP21MX computer either on an IBM-written magnetic tape or, as an intermediate step, to our data base on a CERN HP computer linked to the IBM via the CERNET network. We have thus access to all the standard ESOP software (test programs etc.) developed and maintained at CERN by other groups.

We have also transported and adapted to our HP the FORTRAN version of the cross-assembler [3] . The developement of ESOP trigger algorithms for our experiment is therefore completely performed on our on-line computer.

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[3] We obtained the source program from the Niels Bohr Institute, Copenaghen (UNIVAC 1110).

An HP version of the CERN-written program MICROL loads the object modules from disc files to the processor instruction memory and performs some basic debugging, including instruction and data memory patching, register dumping, and the execution of a set of diagnostic routines.

3.2 ALGORITHMS DEVELOPEMENT

Critical aspects of any trigger system are its efficiency (events lost at the trigger level are lost forever) and its reliability (faults must be detected quickly, otherwise large amounts of data might be invalidated by the suspect of unknown trigger biases). Moreover, debugging should be completed before data taking, not to waste valuable beam time for tests.

We were therefore led to adopt the following method. Montecarlo-generated data files are kept on the HP discs. In a first stage, the candidate algorithm is carefully studied in a quickly written FORTRAN version, running as a subroutine of the HP program "ESOP", and optimized in terms of resolutions,efficiency,background rejection power. We then undertake the sometimes tricky task of coding the algorithm in ESOP assembly language.

The debugging phase is facilitated and speeded up by the availability of Montecarlo events and of a well known FORTRAN simulation of the algorithm. The program "ESOP" loads a M.C. event into the processor data memory, starts the processor and, at the end of the execution, dumps all relevant registers and memory positions, comparing their contents to the results of the FORTRAN simulation. Diagnostic messages and breakpoint-like procedures usually quickly isolate the wrong code within a couple of instructions.

Similar tests can be performed event-by-event on real data coming from the RMH system and are used as a monitor of the processor working conditions in between data taking runs.

3.3 THE STRAIGHT TRACKS REJECTING ALGORITHM

The algorithm we developed uses the encoded hits from four proportional chamber modules (PC1,PC3,PC4,PC6) to calculate the scattering angle.

First of all the hit wires are separated according to the proportional chamber plane to which they belong and the centers of clusters of adjacent hit wires are calculated. The angle θ_x between the incoming and the outgoing tracks projected on the (x,z) plane and the corresponding angle θ_y in the (y,z) plane are then calculated.

The event is rejected or accepted as soon as one of these conditions is satisfied:

1. rejects:

   a) no hits in any of the four chambers;

   b) more than one cluster per projection in any of the chambers measuring the incoming tracks;

   c) more than a preset number of clusters per projection in the chambers measuring the outgoing tracks;

   d) $\theta_x^2 + \theta_y^2 < \theta_0^2$: scattering angle below a given threshold θ_0 ;

2. accepts:

   a) $\theta_x > \theta_0$

   b) $\theta_y > \theta_0$

   c) $\theta_x < \theta_0$, $\theta_y < \theta_0$, but : $\theta_x^2 + \theta_y^2 > \theta_0^2$

The angular resolution of the trigger algorithm, evaluated by a Montecarlo calculation, is shown in fig.3 : the approximations and rounding errors due to the processor integer arithmetic are not spoiling the intrinsic space resolution of the wire chambers significantly.

4. PERFORMANCE

ESOP has been implemented in the pre-existing one-level trigger system of the experiment with a minimum of modifications : the counter trigger initiates the read-out of the PC hits from the RMH system to the ESOP buffer memory ; the end of the transfer starts the ESOP algorithm : a reject resets the whole electronics, while an accept interrupts the on-line computer for the event acquisition.

Besides the necessary arbitration and busy logic, an 'abort' logic provides a general reset if the transfer protocol is not correctly terminated; additional circuits measure and monitor the processor's dead time and the accept,reject and abort rates.

We report here on some preliminary results on the processor performance in a recent data taking run.

4.1 ACCEPTANCE

In test runs both accepted and rejected events were written on tape together with a decision flag set by ESOP. The ratio R of the number of accepted events to the total (accepted + rejected) has been calculated off-line as a function of the reconstructed scattering angle; R is shown in fig.4 for two values of the cut θ_0. These results are in good agreement with what expected from a Montecarlo calculation taking into account the efficiency,noise and resolution of the wire chambers.

4.2 DEAD TIME

The transfer time of PC data from the RMH system to the ESOP buffer memory was measured: 300 nsec per encoded hit are necessary on the average.

The decision time is histogrammed in fig.5 for accepts (a) and rejects (b) : 70 and 90 microseconds are respectively needed on average. These figures should be compared with the typical on-line computer acquisition dead-time of about 2-3 msec/event.

The ESOP dead time has been further analysed as a function of the accept or reject type: the average values are reported in table 1.

In view of a future algorithm optimization, an investigation has been carried out to find the most time-consuming part: as expected,the data decoding and the cluster reduction loops are responsible for a large fraction (75%) of the dead time.

4.3 RATES

The rejection factor provided by the ESOP filter is of course strongly dependent on the selectivity of the counter trigger; in the presence of the small beam killing veto counter F7 it was typically 81% and 85% for cuts in scattering angle of 20 and 33 mrad respectively.

If one wants to limit the dead time fraction due to ESOP to 20% , the maximum acceptable input counter trigger rate is 2300 triggers/sec , or 920 triggers in our 400 msec spill, resulting in 140-170 accepts/spill. In these conditions, the bottleneck is still the computer dead time which limits the useful accept rate to about 200 accepts/sec (80 accepts/spill) for a 50% alive time.

4.4 FUTURE IMPROVEMENTS

The preceding analysis indicates the line we shall follow to improve the filter performance:

1. The leakage of small angle events through the filter (fig.4) is mainly due to spurious hits simulating a large angle track : the requirement that the intersection of the input and output tracks be inside the target fiducial volume should get rid of them.

2. The dead time can be reduced by clustering and reformatting the RMH data in a dedicated processor, the CRN [8]. Some tests have already shown that the ESOP dead time will be lower by a factor 2 : the acceptable input rate will increase accordingly.

3. Larger rejection factors to better match the on-line computer recording capability require more stringent cuts including kinematical conditions (i.e. correlation between scattering angle and recoil energy). Some additional interfacing work is needed to read out the ADCs, however the relative hardware already exists [9].

5. CONCLUSIONS

We implemented ESOP in a HP on-line environment ; we developed a simple filter algorithm, and recorded physics data with a significant improvement in sensitivity.

The choice of a programmable device has proven to be adequate : we estimate that its lower speed with respect to hardwired processors is largely compensated by its flexibility. In fact one may foresee more complex selection criteria based on several different types of detectors or even a change in philosophy : for instance, data might be histogrammed in the ESOP memory so that histograms instead of single events are recorded on tape.

ACKNOWLEDGEMENTS

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FIGURE CAPTIONS

1. The experimental set-up.
2. Correlation between the scattering angle and the recoil kinetic energy in a 2 mm thick scintillator for a preliminary run at Saclay with 825 MeV protons. A cut at 10 mrad in the scattering angle is applied off-line. The curve corresponds to the recoil energy-scattering angle correlation for elastic pp scattering.
3. The resolution in the scattering angle of the ESOP algorithm for Montecarlo events between 25 and 45 mrad.
4. Ratio R of the number of accepted events to the total (accepted + rejected) as a funtion of the off-line reconstructed scattering angle for two thresholds ϑ_0: a) 20 mrad, b) 33 mrad.
5. Histograms of ESOP decision time for accepts (a) and rejects (b) in ESOP cycle units (125 nsec).

Type of decision	% of events	Dead time (µsec)
Reject a	16.5	61.7
Reject b	13.5	34.3
Reject c	1.5	100.2
Reject d	49.3	115.3
Accept a	15.6	61.5
Accept b	3.1	109.0
Accept c	.3	115.0

Table 1

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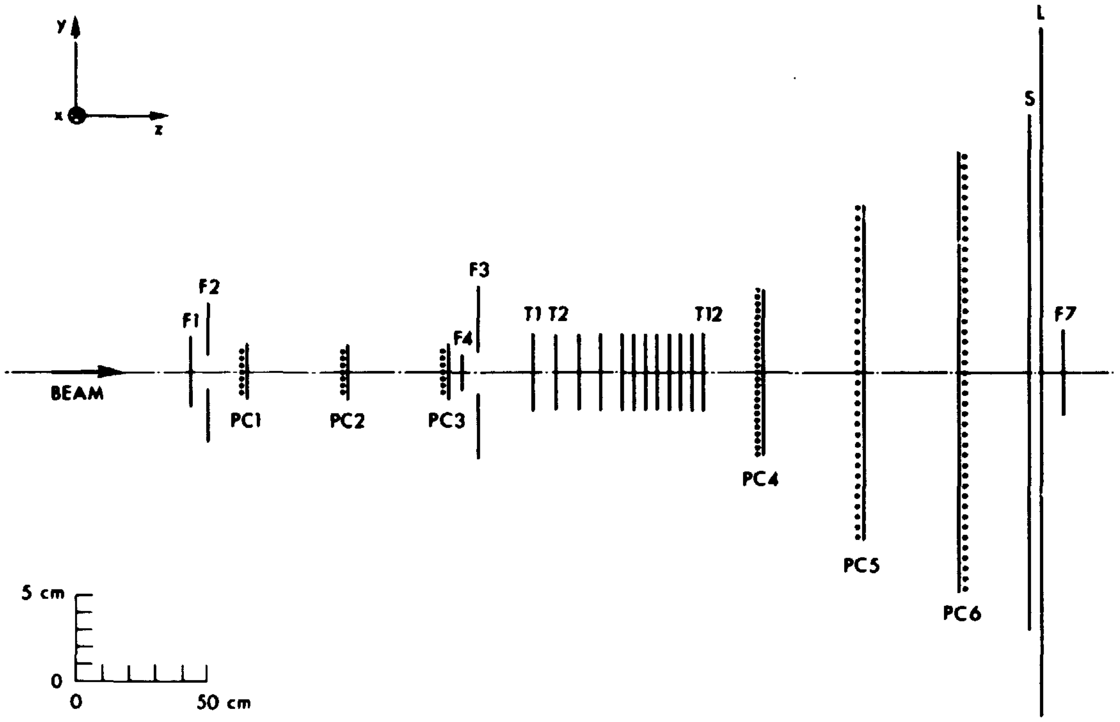

y
x
z
BEAM
F1
F2
PC1
PC2
PC3
F3
F4
T1 T2
T12
PC4
PC5
PC6
S
L
F7
5 cm
0
0
50 cm

Fig. 1

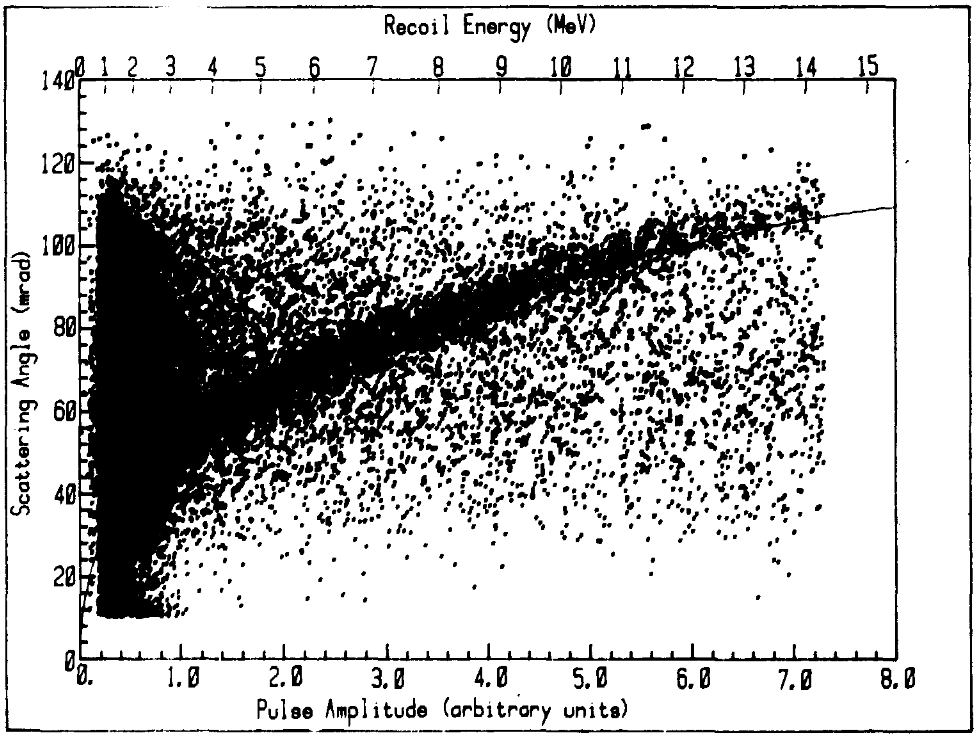

Recoil Energy (MeV)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Scattering Angle (mrad)
0 20 40 60 80 100 120 140
0. 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0
Pulse Amplitude (arbitrary units)

Fig. 2

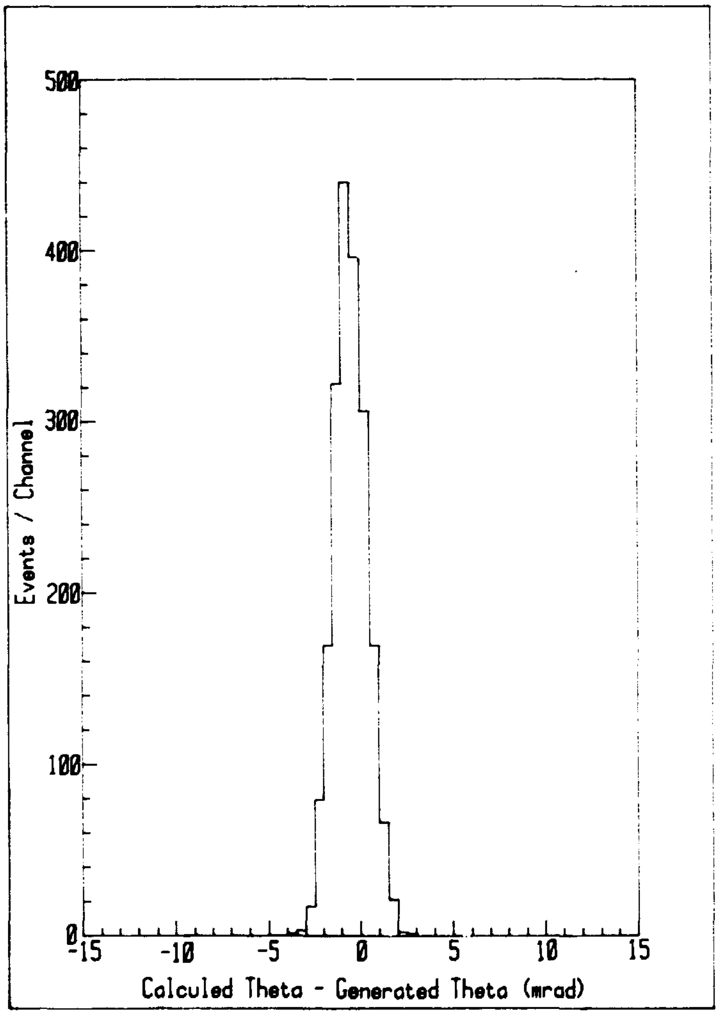
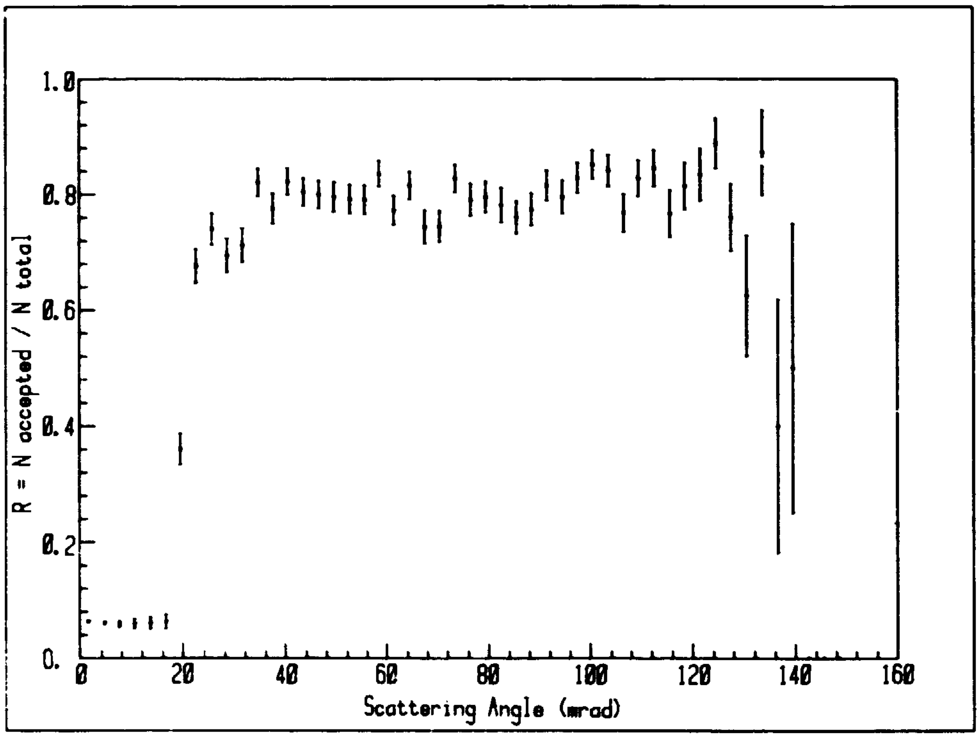
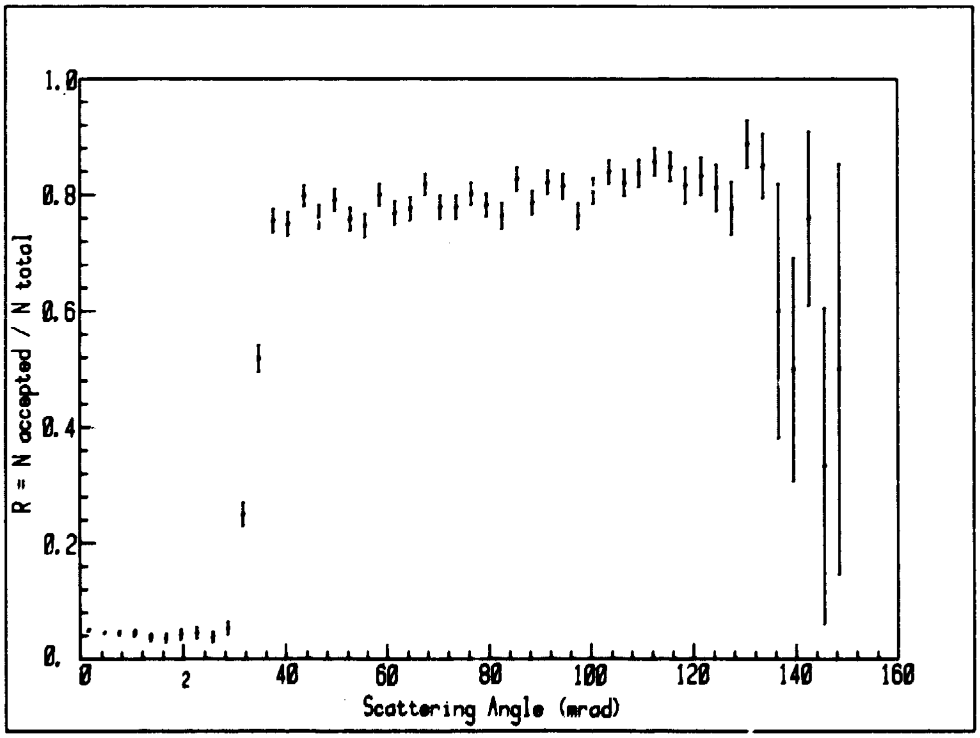

500
400
300
200
100
0
Events / Channel
-15
-10
-5
0
5
10
15
Calculed Theta - Generated Theta (mrad)

Fig. 3



1.0
0.8
0.6
0.4
0.2
0.
R = N accepted / N total
0
20
40
60
80
100
120
140
160
Scattering Angle (mrad)

Fig. 4.a



1.0
0.8
0.6
0.4
0.2
0.
R = N accepted / N total
0
2
40
60
80
100
120
140
160
Scattering Angle (mrad)

Fig. 4.b

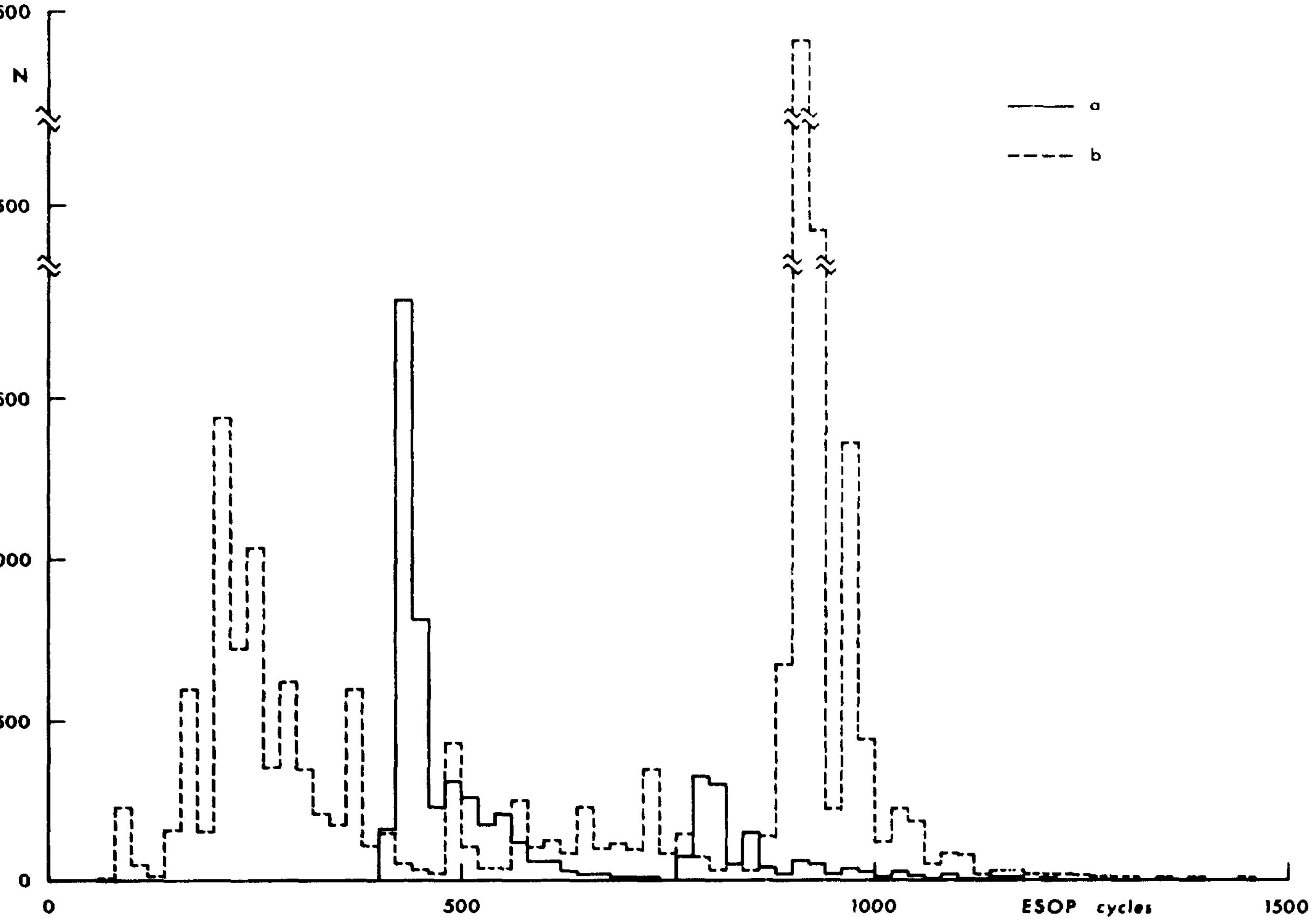


Fig. 5