

BIRTH AND LIFE OF THE BOL-SYSTEM

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INTRODUCTION

This paper deals with the BOL-system as a case study of a computer application in nuclear spectroscopy. "Spectroscopy" however, in a somewhat broader sense than spectroscopists would mean. The outline of the paper is:

- 1) What is IKO
- 2) What is the BOL-system
- 3) What kind of experiments are performed with BOL
- 4) What does the computer configuration look like
- 5) How is it used in experiments
- 6) How did it grow historically
- 7) Some ideas of builders and users now
- 8) Some conclusions
- 9) Some examples

1. WHAT IS IKO?

At the Institute for nuclear physics research (Amsterdam) are working about 250 people in four research groups: beta-gamma spectroscopy, nuclear reactions, electron scattering and radiochemistry; and eight service groups: mechanical, electronic, digital, software, synchro-cyclotron, electron-linac, domestic and administrative. The two accelerators of the Institute are a synchro-cyclotron for protons (45-55 MeV), deuterons (23-28 MeV), ³He-particles (about 69 MeV) and Alfa-particles (45-55 MeV), and an electron linac (85 MeV). A proposal for a 10% duty factor electron linac of 300 MeV is

^{x)} Dr. L.A.Ch. Koerts is gratefully mentioned as the auctor intellectualis and stimulator of the BOL-system, out of the great number of people who were and are involved during its building and usage.

still waiting for governmental approval. Concerning computers: each research group by now has got its own DEC-PDP8 of one kind or another while there is a spare one, mainly in use for off-line development of interfaces. Besides, the Institute has got a medium size computer, a Philips-Electrologica X8, which is an essential part of BOL.

2. WHAT IS THE BOL-SYSTEM?

BOL, the dutch word for "sphere", is used to measure coincidences between charged particles emerging from nuclear reactions in a target during bombardment with one of the extracted beams of the synchro-cyclotron. The maximum solid angle around the target, with detection sensitive surface is 10%, meaning 1% mean coincidences efficiency, but these figures of course are depending on the specific experiment. Parameters that are registered for every particle of a coincident event are: particle type, energy and angle. Since all different kind of particles, at different energies and angles are measured simultaneously, processes are automatically normalized relative to each other. Events are stored on magnetic tape for off line analysis afterwards (fig. 1, 2).

The following sections will deal with:

- 1) the scattering chamber
- 2) the detectors
- 3) the measuring electronics
- 4) the computers

2.1 The scattering chamber

The scattering chamber consists of several layers. The inner one is a spherical shell of 16 cm diameter, containing the target in its center. It has some 64 holes into which detectors with some electronic circuitry are inserted. The shell is cooled down during operation to -20°C . The second layer is a vacuum cooling shell of about 70 cm diameter. More electronics is directly connected to the inside-vacuum part here. The last layer of about 120 cm diameter serves

as a reservoir for aircooling of the outside-vacuum electronics. The holes in this cooling sphere were machined to 50 μm insuring accurate positioning of the detectors.

2.2 Detectors

Two sorts of charged-particle detectors are used in each of the 64 holes: a stack of about 4 mm thick Si(Li) PIN ones and a position sensitive gold layer surface barrier detector the so called checkerboard detector of .3 mm thickness. The latter contains perpendicular strips on front and backside, providing a 1° angular resolution. The checkerboard detector is used at the same time to determine the angle of emission of a particle and its energy loss. The total stack measures the total energy of intruding particles, since they are stopped. These two energy values serve also to identify the particle type.

2.3 Measuring electronics

We distinguish three main units in each detection-channel: detection unit, ADC-unit and logic unit. The detection unit contains the charge sensitive amplifiers still inside the vacuum of the scattering chamber and some more amplifiers and shapers outside the vacuum, a.o. for generation of position indication signals. Logic signals are sent to a logic unit which will help to determine coincidence relations and eventually store the data. Analog signals are sent to an analog unit which eventually will digitize them and store them also. One particle then is characterized by a word of 72 bits. The logic and ADC units are housed in "tuns", the latter containing also a coincidence unit and part of the computer interface unit, the sequencer.

2.4 Computers

A PDP8 is connected to the experiment. It takes data and stores them on magtape or it sends data directly to the EL-X8 computer, a facility which is essential in the stage of setting up an experiment. A second PDP8 can be used for data

taking in stead of the first one. It has no magtapes, but can also direct the data to the X8. Data are displayed by means of a storage scope or line printer.

3. WHAT KIND OF EXPERIMENTS ARE PERFORMED WITH BOL

The main feature of the experiments is, that they are kinematically complete, meaning that at least as many parameters are measured, as is the number of degrees of freedom for a particular experiment. Also data do not cover only the reaction plane, but many different angles. Some topics are the following:

- Few nucleon reactions

$p(d,pp)n$.

The BOL measurement typically lead to data not only in the regions where two-body processes dominate, but also outside of the reaction plane, where hardly any earlier experiment is available. FSI and QFI where compared with model calculations, also a Fadeev one. Interference effects were studied.

$p(^3\text{He},pd)p$, $d(d,pd)n$, $p(^3\text{He},pp)d$.

Strong contributions from quasi two-body reactions (FSI, QFS) were found. Discrepancies from model calculations appear especially in the interference region.

- Break up of ^3He on verious nuclei:

^9Be , ^{12}C , ^{27}Al , ^{197}Au .

The latter reaction $^{197}\text{Au}(^3\text{He},pd)^{197}\text{Au}$ shows a preference for elastic break up leaving the gold nucleus in its ground state. A strong directional correlation between p and d is observed. Use is made in the experiment of so called "local coincidences" i.e. coincidences within the detector.

- Sequential reactions like $(\alpha,2\alpha)$.

- Particle unstable nuclear systems, like p^2 , (pd) , ^5Li , ^8Be , $^{12}\text{C}^*$.

For instance in the latter experiment $^{12}\text{C}(d,d')^{12}\text{C}^{\times}$, $^{12}\text{C}^{\times}\rightarrow^8\text{Be}(g.s)+\alpha$, the angular correlations have been studied in and out of the reaction plane, and have been compared to model calculations.

4. WHAT DOES THE COMPUTER CONFIGURATION LOOK LIKE

The PDP8 normally used for data taking is a 4k, 12b, 1.5 μs machine with teletype, two magtapes (556 bpi, 30 ips), a clock, a storage scope and a keyboard (fig. 3). Naturally it is connected to the measuring electronics. It also has a memory to memory link with the X8. This link under X8 program control can be switched to either of the two PDP's. The other PDP has got 8k of memory, a teletype, a tally papertape punch and read, a magnetic disk (64k), and four video terminals. The experiment can be plugged into a somewhat simplified I/O buffer, connected to this PDP, a facility which is used only when the other PDP is down at a critical moment. The X8 is a 27 bits, 48k, 2.5 μs machine. It has got four telex-consoles, 5 magnetic tape units (800 bpi, 150 ips) a magnetic drum (512k, 21 ms) a 1000 ch/s paper tape reader, a 150 ch/s punch and a 10 lines/s line printer. The tape unit interfaces of the PDP are home-made. They are normal "IBM-compatible" from a tape point of view extended with a so called scatter read facility. This means, that one block, during reading can be sent to non consecutive memory parts. It is used f.i. when reading a program from tape which is longer than one memory page. An analogous facility is used in the interface to the X8, but here also a gather-write is possible. The PDP-station serves also as a data display terminal for the X8.

Something about the software

The X8 is used in time-sharing, the system being called WAMMES. Experimental data are handled with the so called WINDOW-system (figs. 4,5). In the first place the latter system provides a high-level "language" for I/O handling: all

I/O channels look the same to programs in this language. In the second place it provides an easy way to deal with the hierarchically organized data at different levels (viz. appendix 1). The experiment-PDP is equipped with a similar, but of course much simplified version of the window idea under supervision of a monitor. Most data taking and primary datahandling programs are standard with convenient control options. The other PDP is used for other than BOL tasks, mostly in cooperation with the X8.

A conversational symbolic programming language called SIMPLEX, somewhat analogous to ALGOL60 has been incorporated into the window system. This combination proved to be very effective for convenient datahandling: the simple I/O and hierarchic handling of the window system together with the simple computational solutions in SIMPLEX.

An other important software part is formed by all kinds of editing programs and magtape program library handling programs.

5. HOW IS IT USED IN EXPERIMENTS

The second thing to do in a experiment, the first being a gross check of all system parts, is to focus the beam on the center of the target, with the help of several magnets. One can do it by looking on a fluorescence screen or what so ever, but the required measuring accuracy is 1° implying an accuracy in position of a few tenth of one mm and of an accuracy in direction of also a few tenth of a degree. An obvious solution is to do an experiment which is sensitive to these parameters and which will take only a short time, so that measuring and adjustment can be iterated. So one takes f.e. a hydrogen target (CH_2) and bombards it with the beam, looking for elastic coincidences between beam particles and protons. This measurement is "more than complete" with regard to the kinematic variables. By measuring with combinations of detectors in perpendicular planes one can calculate the beam position. This experiment is performed on-line with the X8, which takes data via the PDP and evaluates the position.

Normally the gross adjustment measurement takes a few minutes, while the fine adjustment, depending on required accuracy takes 15 to 30 minutes. The incoming events in this case are stored on drum. The physicist has a X8-telex available near his experiment operating desk, where he gives his commands and gets his answers.

Next in the experiment comes data taking. The X8 is not used in this stage. The PDP takes data, stores them on mag-tape, and prints a log on a teletype. One tape-take may last from 10 minutes to several hours. A run lasts for about one week, typically yielding a hundred tapes. Depending on the experiment the PDP may discard data but normally all incoming events are stored, i.e. 72 bits per particle, one particle for singles, two for two-fold coincidences, more for higher-fold coincidences. Singles and coincidences are measured separately in time, and are recorded on different tapes. Since commonly we intend to measure coincidences, only a minor fraction of singles tapes is recorded for later checks on several system parameters.

The following stage in an experiment is to calibrate energy scales and for all events convert ADC-output values into energy-values, to convert energy and energy-loss into energy and particle-type, to convert detector and position values into angles and to regather coincidences of one and the same reaction-event. In this stage the X8 is used intensively, reading and writing tapes, plotting spectra on the line-printer all in close conversation with the experimenter at the telex. The drum now is used for histogramming of data, which then can be visually inspected via the line-printer or PDP-storage scope. So here the display function of the PDP enters the game, the X8 having no scope display of its own, and it will play this role all along the data handling.

The step next normally is one of selection. The experimenter chooses particular particles, reaction Q-values and other parameters, in fact, a particular reaction process or class of processes. Note that all data are still available,

so that even if the chosen process was the pertinent aim of the experiment, later on other processes which occurred at the same time, can still be evaluated when interest for them arises after interpretation of the originally desired data. This possibility is used quite often and is one of the very advantages of BOL. In a way the beam plus target reactions are on tape like high energy physicists have them on photographs.

Now more and more computations enter further data handling such as center-of-mass transformations, and again the drum is used for histogramming. One important thing has to be done yet, namely the normalization for detection efficiency. Several procedures have been used to do it, one using a monte-carlo technique: in the center of mass weighed random events are generated and transformed to the lab system according to the kinematics of the selected process. Now the detection sensitive area is taken into account and the resulting data are stored on magtape, thus simulating an experiment. So these data, when handled like experimental ones, yield the phase space distribution of the process, corrected for detection-geometry. The CERN random generator is used in this program. When all this has been done, the next step is to collect the data in physical interpretable histograms f.e. a Dalitz plot (fig. 6) and eventually compare the results with model calculations. Now the scope display is used intensively together with a hardcopy output when one is satisfied. The programs to perform the above things commonly are written in SIMPLEX, while several standard programs can be used such as a program to display pictures in perspective under variable looking angle and distance.

6. HOW DID IT GROW HISTORICALLY?

When in 1965 BOL was conceived kicksorters were still at the top. So we looked into a "very special" option available for our very modern 4k kicksorter, i.e. a buffer unit which could dump the kicksorter memory on magtape. Then we heard about some new small cheap computer to be used as a

programmable kicksorter, the PDP8. For both solutions we needed of course a larger computer to analyze the data.

The PDP was equiped with two cheap magtape units. To save money and to get into the field of interfacing we decided to design and to build the tape interfaces ourselves, which also would allow us to taylor it to our wishes! Now 4k of still available hardwired kicksorter memory can not be left unused by a physicist, so this memory would function as an autonomous display unit memory. A "highbrown" interface to the PDP was build complete with "jump" instructions to reduce flicker, light pen, top view and isometric display, with variable angle and light intensity variation. A memory to memory connection with the X8 was disigned by us, and when the second PDP8 came in, certainly it had to be connected to the other PDP8. Still later the X8 connection was changed into a switch for both PDP's. The last PDP would serve more as a separate display unit, since the other would be rather busy with data taking. So a storage scope and hardcopy unit came in. The first interface boards where rather special purpose, but right now the digital group, born in meantime, has its convenient standard boards and methods.

Parallel with hardware the software developed. The window system for the X8 first, together with a simplified version for the PDP8. The X8 manufacturer delivered a time sharing system, but not at the first hardware delivery. For the PDP8 a more simple monitoring system was written by ourselves. Lots of editing programs were made and the window system was growing. A software group had been born, which a.o. remade the time-sharing system and then X8-use really started, experimental tapes coming in now and then already. Several standard data-handling programs had been written within the window-system and SIMPLEX was born. A three structured histogramming program was implemented. Of course many more important developments, could be mentioned, but let me conclude this section by telling what we use with satisfaction and what not. Not used are: the highbrow hardwired display unit, the inter PDP coupler. The tape interfaces were re-

designed even before testing. In the software several "standard" data handling programs are dying. But really all the rest is used satisfactory, though of course many minor changes in both hard- and software have been incorporated.

7. SOME IDEAS OF BUILDERS AND
USERS NOW

The systems philosophy of BOL could be allegorized as: record everything now, analyze it later. Among others, this lead to a rather fixed hardware part including for the sake of argument the measuring electronics in the hardware, which for some experiments is felt to give too much non-specific data handling. But it also enables immediate measuring in regions of space where one is not sure a priori that it is worthwhile, and it has shown worthwhile in several instances. Also the simultaneous measurement of different processes leads to relative normalization, independent of beam current. And the kinematical completeness of measurements can be regarded as a virtue by itself. In contrast to the hardware rigidity, the software is rather flexible: in one program, on a high level one can deal with I/O problems and calculational tasks but one can also easily insert assembler code parts. These possibilities are fruitfully applied in program building and especially in non-standard data handling programming. But for standard data handling the very flexibility may become a burden since it consumes time. Time is felt as a problem through reliability also: for each run tests and calibrations have to be performed and some people regard the elapsed time between recording and first physical data output almost too long keeping involved sufficiently. But this seems not to hold for BOL only.

Though man-machine interaction is rather satisfactory (almost all programs are conversational via telex) the interaction could still be improved. Most of us agree on the success of some things: the partitioning of tasks between X8 and PDP's, the time sharing system of the X8, the great number of editing facilities, the common way to deal with data

in general, the I/O solution, the display station, the drum as a huge kicksorter, the array handling programs, and as a whole the possibility to perform complete measurements over a wide field of parameter values in many dimensions. An analogous discussion could be given about the non-computer parts of the measuring instrument.

8. SOME CONCLUSIONS

Building of the BOL system was a learning process to most of us and it certainly brought know-how into the Institute. Now after building and after some years of usage the following points may be important enough to be mentioned as a sort of **personal** conclusion.

- A time sharing system speeds up program development tremendously.
- So do editing programs.
- Modularity is an aid to optimize the system. This holds for measuring mechanics and electronics, computer hardware, and computer software.
- Convenient standard building blocks on different levels are an aid to modularity. A convenient degree of modularity, I guess can only be found by iteration.
- Users experience and feedback are other aids to optimize the system. Modularity helps feedback through getting users experience on parts of the system and through making changes easy.
- Feedback may help to make the choice between a general or a specific data handling solution.
- Man-machine interaction should be strongly man oriented. This has been said so often, that repetition seems superfluous. I think the essential problem is, that just how strong "strong" is to be can only be grasped by experience. Shortly, though we know BOL can still be optimized, we feel that it is useful for the purpose it was intended.

English publications of "technical" data on BOL are:

- 1) "The BOL nuclear research project", L.A.Ch. Koerts et al., Nucl. Instr. & Meth. 92 (1971) 157.
- 2) The scattering chamber of the BOL-system, K. Mulder et al., Nucl. Instr. & Meth. 92 (1971) 161.
- 3) Position sensitive detector telescopes for charged particles used in the BOL-system, J.A. den Boer et al., Nucl. Instr. & Meth. 92 (1971) 173.
- 4) Electronics of the BOL-system, J.E.J. Oberski et al., Nucl. Instr. & Meth. 92 (1971) 177.
- 5) The BOL computer hardware configuration, J.E.J. Oberski et al., Nucl. Instr. & Meth. 92 (1971) 189.
- 6) Test procedures for the multidetector BOL-system, M.A.A. Sonnemans et al., Nucl. Instr. & Meth. 92 (1971) 193.
- 7) Data acquisition with the BOL nuclear detection system, R. van Dantzig et al., Nucl. Instr. & Meth. 92 (1971) 199.
- 8) Analysis of multidimensional nuclear data (BOL), R. van Dantzig, Nucl. Instr. & Meth. 92 (1971) 205.
- 9) Coincidence measurements on break-up of few nucleon systems with the multidetector BOL, R. van Dantzig, doctor's thesis 1971.
- 10) The nuclear reaction ${}^3\text{He}+p\rightarrow p^2+d\rightarrow p+p+d$. Correlation measurements with the multi-detector BOL, K. Mulder, doctor's thesis 1971.
- 11) An alpha-deuteron correlation experiment on carbon with the multidetector BOL, J.E.J. Oberski, doctor's thesis 1971.
- 12) A coincidence study of some few nucleon reactions, B. Wielinga, doctor's thesis 1971.

Papers at the conference "few particle problems in nuclear reactions", (Los Angeles, August 1972):

- 13) Three-body reactions studied with "BOL", R. van Dantzig et al.
- 14) Angular distributions for the reactions ${}^3\text{He}+p\rightarrow d+(pp)$ and ${}^3\text{He}+p\rightarrow p+(pd)$, B.J. Wielinga et al.
- 15) Treiman-Yang test for $d+d\rightarrow d+p+n$, A.D. IJpenberg et al.
- 16) Peripheral break-up of ${}^3\text{He}$ on ${}^{197}\text{Au}$, W. Hermsen et al.
- 17) Experimental tests on the purity of nucleon 1S_0 final-state interaction, R. van Dantzig et al.
- 18) A study of the reaction $p(d,pp)n$, B.J. Wielinga et al.
- 19) Prominent two-body effects in the processes $p({}^3\text{He},pd)p$ and $d(d,pd)n$, B.J. Wielinga et al., Phys. Rev. Lett. 27(1971)1229.

APPENDIX 1

In fig. 5A, the name "INFO" in the macro "IN" can be any of the following flows:

<u>name</u>	<u>function</u>
TX	from mag.tape to X8-memory
AX	from drum-array to X8-memory
BX	from paper-tape to X8-memory
PX	from PDP8 to X8-memory

Similarly the "OUTFO" in OUTPUT can be:

<u>name</u>	<u>function</u>
XT	from X8-memory to mag.tape
XA	from X8-memory to drum-array
XB	from X8-memory to paper tape
XR	from X8-memory to line printer (several formats a.o. tabel, topview)
XP	from X8-memory to PDP8.

The name "IR" is for IKO-Rekord. It is the smallest info-quantum in the hierarchy:

IR, BLOCK, TRAIN, NET, GROUP, FILE, REPFIL

Commonly it is a 72-bits experiment data word, but it can be anything else. The structure of an IR is defined by a so called "chord" definition, specifying a sort of variable byte-structure: Example:

```
1          "identifier"
3          "number of X8-words"
5;5;1;1;6;6;  "number of bits/byte; idem...., word 1
12;3;9;      "number of bits/byte; idem...., word 2
3;9;1;1;1;1;7;  "number of bits/byte; idem...., word 3
```

This is the structure of the experiment data word in the X8, two PDP8-words (fig.4) being packed into one X8 word.

For drum arrays the following hierarchy exists:

GROUP, ARRAY, ROW, COLUMN, AR

AR, Array-Rekord, being the lowest quantum.

The drum, used as a huge kicksorter, can be divided according to the so called group-definitions.

There are four classes of groups with the following group-

numbers

	<u>group</u>	<u>function</u>	
class 1:	0-31:	histogramming in full	word length: 24 bits
	32-63:	histogramming in $\frac{1}{2}$	word length: 12 bits
	64-95:	histogramming in $\frac{1}{4}$	word length: 6 bits
	96-127:	hitogramming in $\frac{1}{8}$	word length: 3 bits

Example:

3	"number of groups to be defined"
0;5;1;4096	"group identifier, number of arrays, number of rows, number of columns (drumspace: 20k)"
32;5;1;4096	"etc.(drumspace: 10k)"
72;64;64;64	"etc.(drumspace: 64k)"

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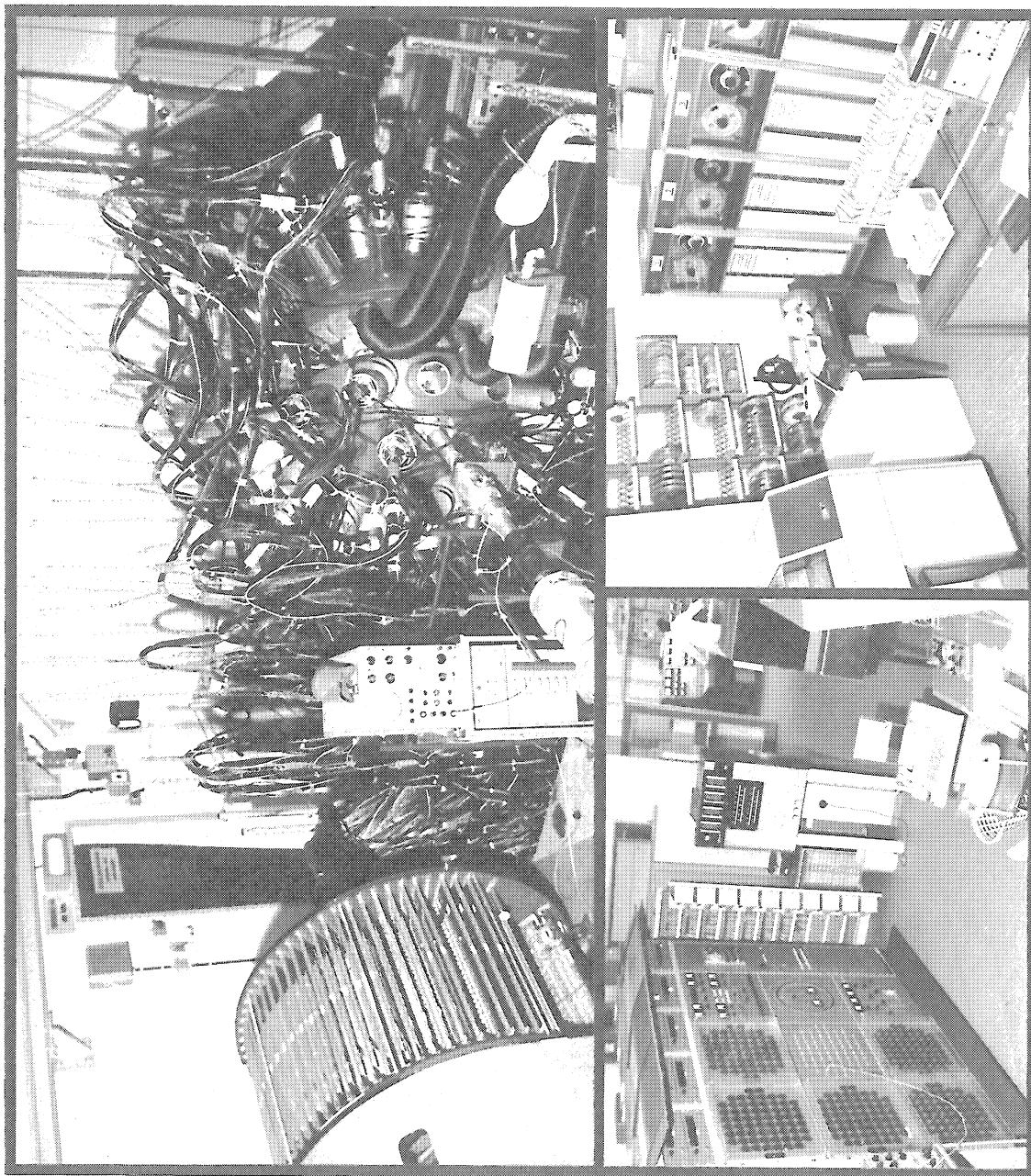


Fig. 1 Upper: the BOL scattering chamber with the tons containing ADC-boards at left, beam entering from front, most detection units inserted.
Lower left: operating panel, DEC PDP8 and display terminal.
Lower right: EL-X8 computer.

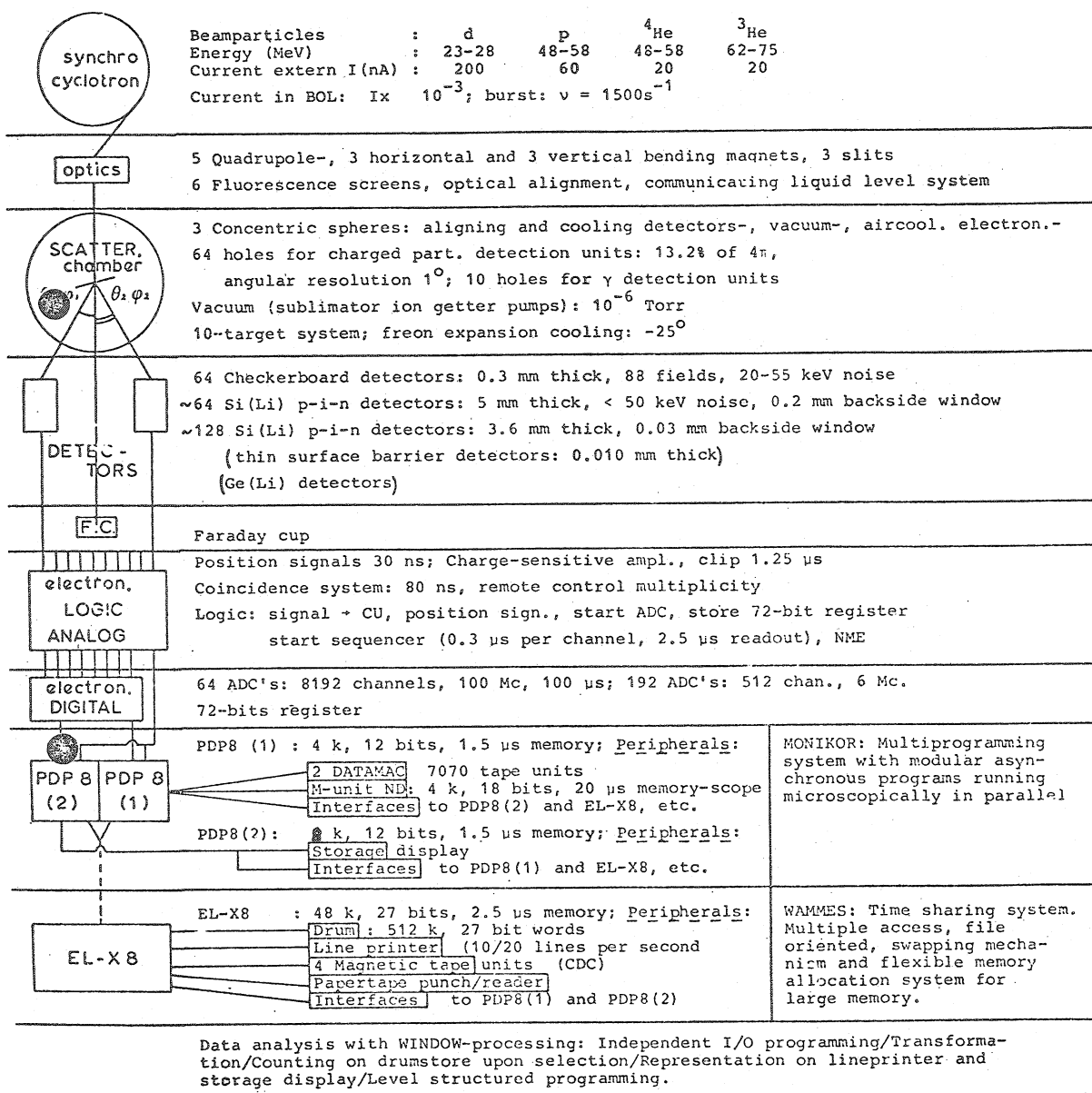


Fig. 2 Schematic survey of the BOL system

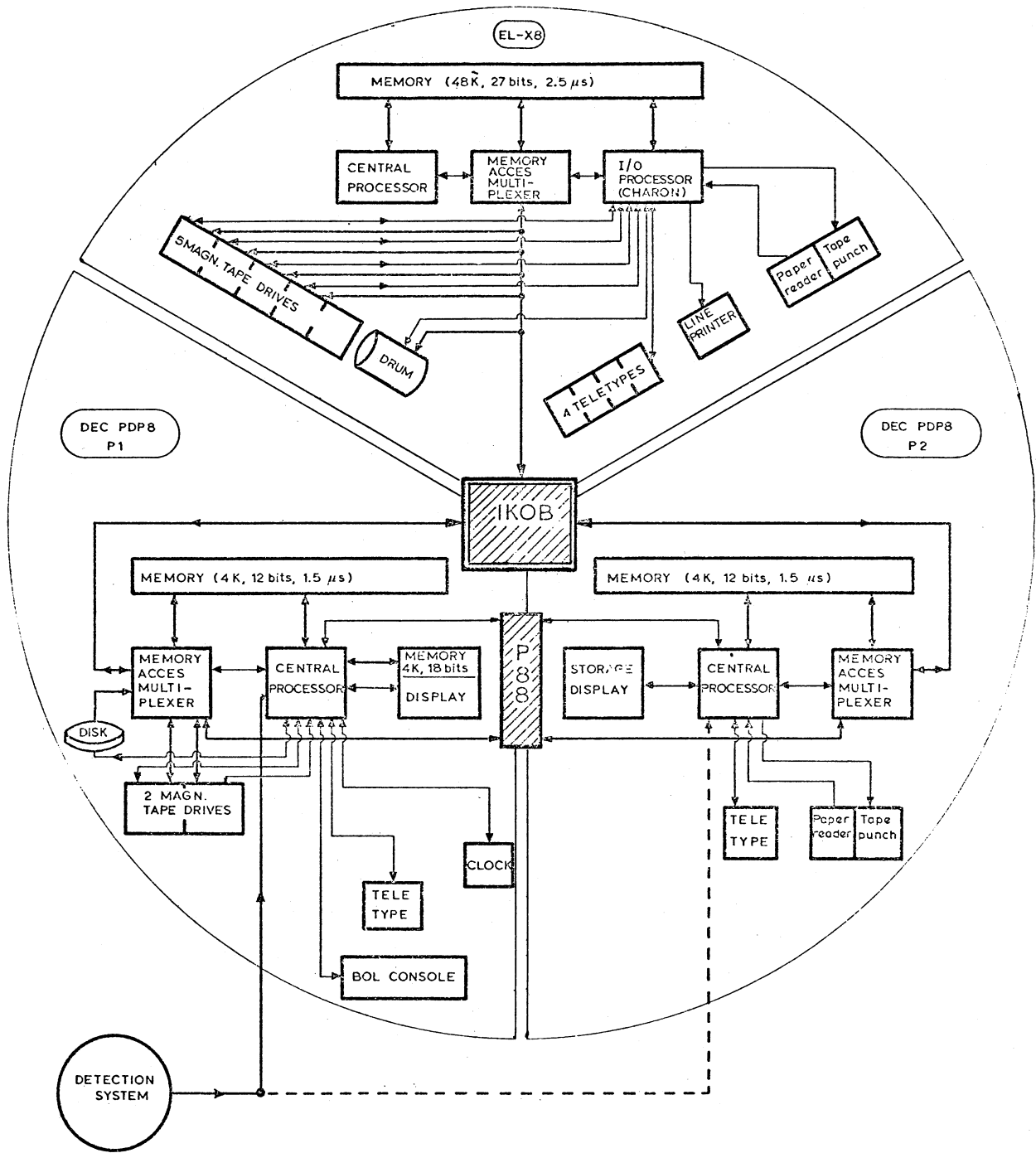


Fig. 3 Survey of the BOL computer configuration

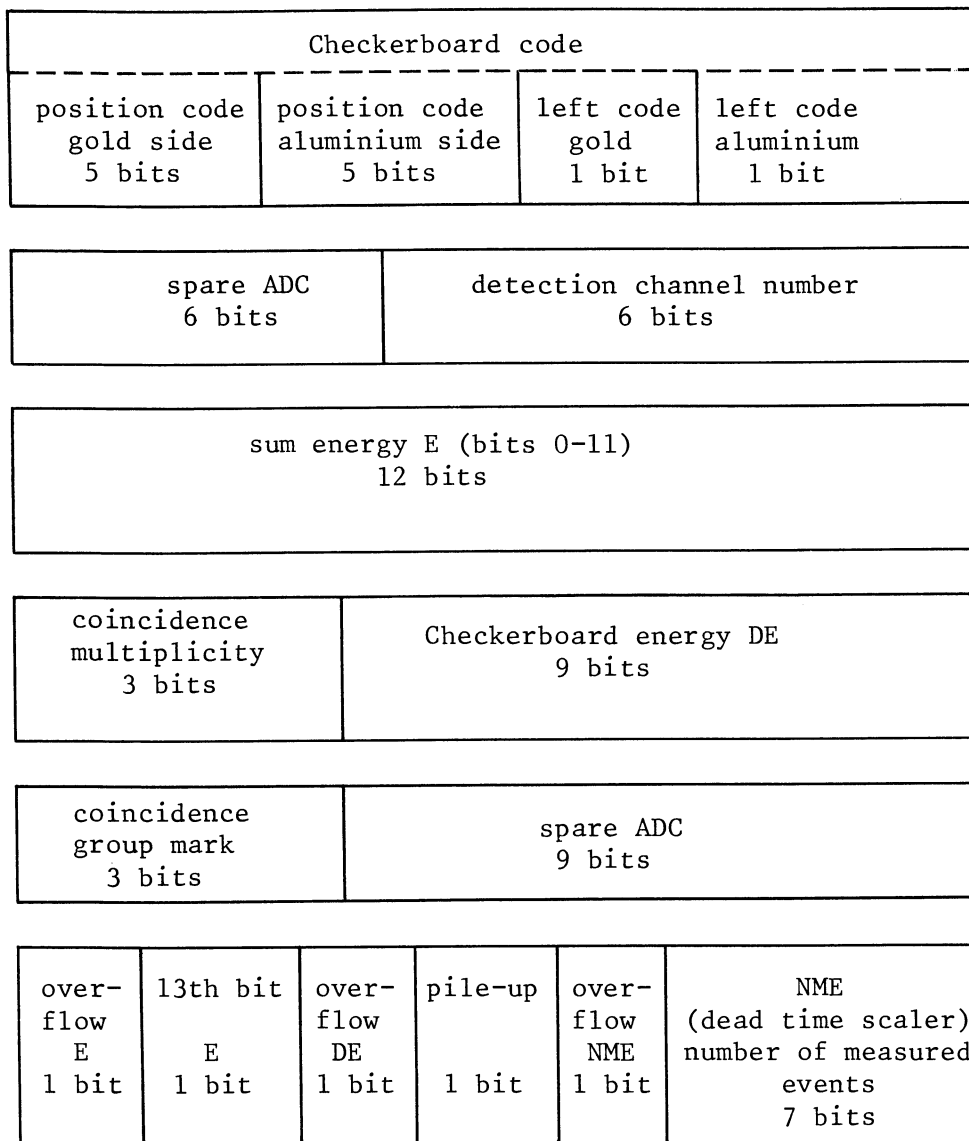


Fig. 4 Construction of a 72-bits data word, the most raw form of stored information.

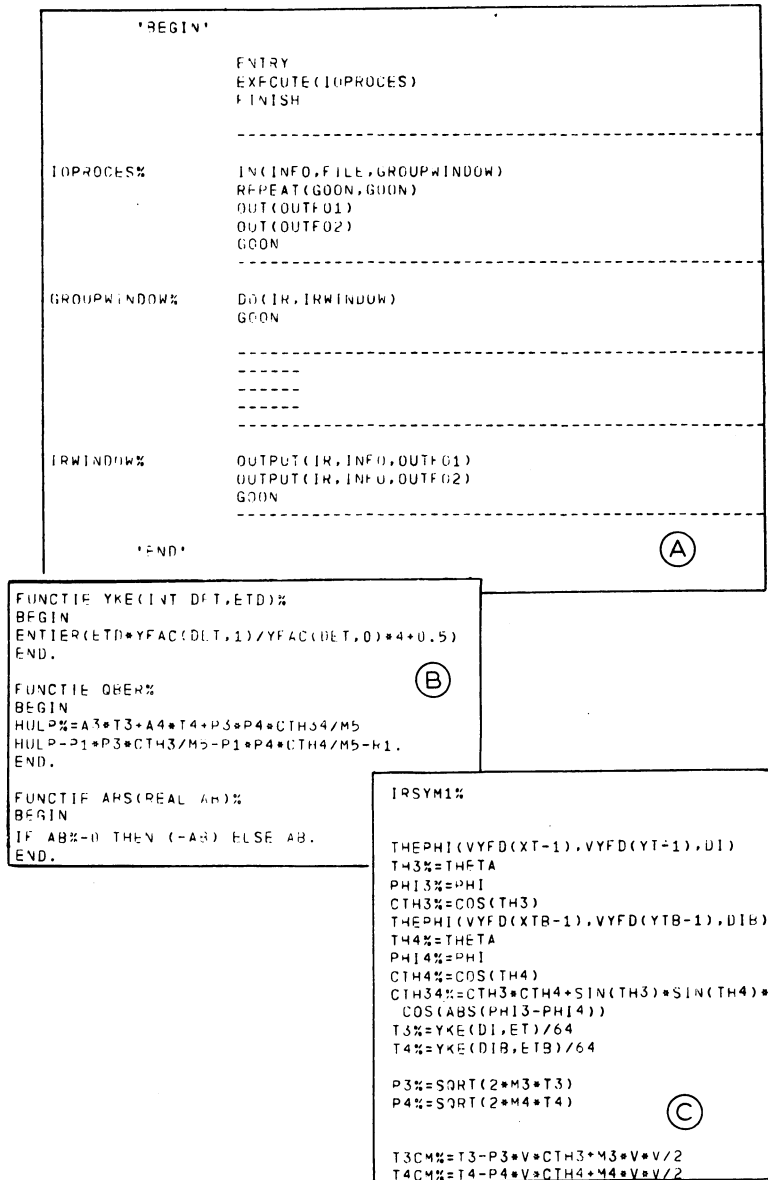


Fig. 5 A: an example of a simple WINDOW program
 B: part of a function detection in SIMPLEX
 C: SIMPLEX part executed within a window program to calculate center of mass energy for each particle

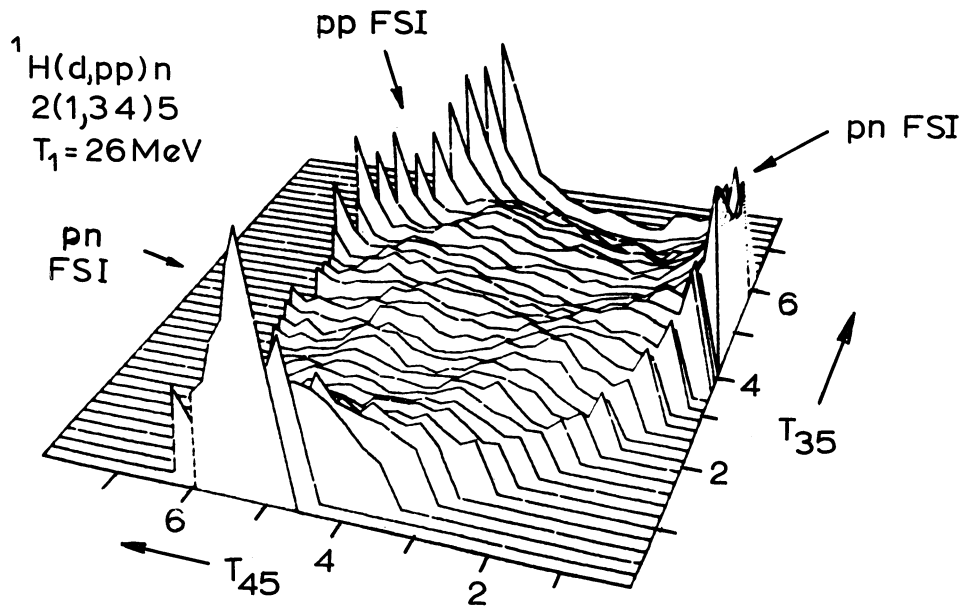


Fig. 6 Dalitz spectrum, a highly analyzed form of the measured data