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FAST TRIGGER TECHNIQUES

by

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Fast Trigger Techniques

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DESY, Hamburg

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Summary

Electronic systems which recognize useful reactions and reject most background within a few microseconds are discussed in connection with their application in electron positron storage ring experiments.

Fast Trigger Techniques.

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1. Introduction.

In this notes several aspects of the fast trigger techniques used in electron positron storage ring experiments are discussed, with the intention of being of some help for the preparation of future detectors, in particular for LEP. Let us first define the trigger task in general, and specify the part of the problem which will be considered here.

The performance of existing electron positron storage rings has deeply influenced the design of the experiments and the organization of the groups of physicists working on them. Low rates of extremely valuable events and small number of interaction regions are the dominant factors. Most detectors tend to be 'universal' and as many as possible of the reactions taking place must be recorded. Each group involved in such an experiment must be able to handle almost every physics subjects coming up. This at least is the tendency.

The rates for 'good' events are so small (due to luminosities and cross sections) that all data having some chance to be useful must be stored for later analysis and, to avoid losses, a lot of background is included. There is however a limit for such storage: It must be possible to reanalyse the stored data, in general several times, for different physics subjects (see Fig.1). Cheap mass storage is still made on magnetic tapes. Their reading time imposes a limit on the total amount of tapes. Reading and analysing about a thousand rolls of tape is still a major job for any computer center. However, very exceptionally data from more than about two years of run is re–analyzed. Taking these facts into account, most groups consider a few rolls of tape per day as an upper limit. This means also that only a few events per second (running time) can be permanently stored.

Every selection step, between data production and the permanent storage as defined above, must be considered as definitive and can be included in a generalized concept of 'trigger'. A selection step which takes too much computer time to be repeated should be performed as soon and as fast as possible, in order to save valuable manpower and computer time.

The input rate of the selection chain, on the other side, can not be greater than the bunch–crossing rate. For LEP this will be 40.000 per second, equivalent to a bunch to bunch time of 25 microseconds. In the following we will consider as 'fast' any operation (selection) made in less than 20 microseconds. Such an operation could be performed at each bunch crossing and would not introduce any dead time.

The overall trigger task consists then in reducing the rate of accepted and stored events to a few per second or less. The subject of the present notes consists in discussing how much of this work can be completed within the first 20 microseconds after a bunch crossing.

2. Some Historic Remarks.

Ten years ago the problem was not so much the trigger of a detector covering most of the solid angle around the interaction point, but rather how to built such a detector. Cylindrical Charpak chambers were new and some of them were just built at DESY. In 1972 the first big cylindrical drift chamber was successfully tested but there was no mass-produced time digitizer to run it. Electron positron physics at that time was done with spark chambers, at Frascati, Orsay, Novosibirsk and Boston. They were triggered by big plastic scintillators.

While cylindrical chambers were developed at DESY, first tests to use multiwire chambers to trigger themselves were started in collaboration with a group at the storage ring ADONE in Frascati. It was first of all learned there that proportional chambers could be placed very near to the vacuum pipe. A first track sensitive trigger was made in 1972. It used what later is called a "sequential shift register logic".

Track recognition was a well known subject to bubble chamber physicists. A device particularly developed to perform such a task (on line, during the measurement of a picture) was the spiral reader. It used the advantages of cylindrical coordinates for fast track-following computer programs. Such a device was already described by McCormic in 1958 in a bubble chamber meeting at Brookhaven. The rotation of the picture with repeated use of the same routines for track following was the guiding idea for track sensitive triggers for cylindrical wire chambers. During most of the year 1973 a set of such cylindrical chambers – 1.8 meters long – was operated successfully at ADONE with a trigger logic which was the model for many later developments. It was called MADKA (see Fig.2), was later improved and used by the BONANZA group at the storage ring DORIS and is still in use on a synchrotron in Bonn. It could probably be used at LEP too.

At ADONE the main result consisted in demonstrating that track and shower recognition (and counting) were good methods to separate beam-beam events from beam-gas background. Showers were recognized as conversion pairs in a lead shield mounted between the chambers. Events for which the sum of tracks and showers was greater than three, had hardly any background. Instead, one- and two-track events were mostly background and their rate was prohibitive. This situation is still happening in present day experiments (i.e. at PETRA).

It was also recognized that many tracks from beam-gas events had small transverse momenta and that only 'hard' tracks, penetrating 5 mm of lead and 10 mm of aluminium could be used in the track-count for good events. This corresponds, in our present magnetic detectors, to a cut in transverse momentum.

Obviously all these facts were also well known to other storage-ring experimentalists at that time. Interesting for our discussion is the fact that such criteria could be used within microseconds in a fast trigger.

Since then, cylindrical devices including wire chambers became standard and many technically different solutions for the trigger problem were found. They all perform a 'pattern recognition' operation. Tracks (and also other configurations like showers) are recognized by comparison with thousands of preestablished masks. To define these masks, a few words should be spent on the expected types of events, their rates and on the detectors used at present.

3. Events.

Fig.3a shows a set of events which are expected at electron positron storage rings. The picture is ten years old (1). Rates observed later were written in. The importance of track recognition is quite obvious. However, some special types of events had to be added. They required improvements of the trigger logic. Such events are shown in Fig.3b. Additional conditions coming from myon detectors and small angle counters (tagging systems) had to be included in the decision logic. Particular care must be taken with jets. They may be confused with small clouds if the track finding device can not identify some well defined track. Low energy jets like those appearing in photon photon interactions may cause additional problems.

As already mentioned, the recognition of tracks of charged particles is a very important criterium to select events, in particular on storage rings with bunched beams. It allows to discriminate against background events (cloud-like events) which are mainly due to beam gas collisions. In fact, the presence of a well defined track is still the best help to recognize good events originated in beam-beam collisions. The source coordinates (along the beam) provide a so called Z-plot which should present a peak at the interaction point. However, only one track recognized is not enough to reduce the rates sufficiently. In the absence of other criteria (like energy) two or even three tracks must be required to define a good event and simultaneously reduce the background to less than a few events per second.

The energy deposited in shower counters or hadron calorimeters or the presence of penetrating myons are also used to take trigger decisions. This type of trigger is in general made with standard electronics (NIM) or it is built using fast integrated circuits with similar speed characteristics. Such trigger conditions are usually combined with the 'track' trigger in a subsequent 'decision logic' which will be discussed in chapter 8.

The total energy deposited in the detector, the 'visible' energy, is a very important parameter. A plot of this energy for all stored events should present a peak at twice the beam energy and another one at very low energies. This low energy peak is due to beam-gas, QED and photon-photon interactions in which most of the energy escaped through the beam pipe. While there is no serious trigger problem for the events in the high energy peak (most events have several good tracks), there are difficulties selecting events with low energy. In addition to the fact that the total energy is no longer a good criterium to distinguish events from background, the available tracks have often small transverse momenta and in some cases (due to the magnetic field) only reach a few chambers of the detector. Such events require special attention in the design of the trigger.

4. Detectors.

Most detectors for electron positron experiments look like the "typical universal detector" shown in Fig. 4. The question is, which of the many different components of such a detector can be used for a fast trigger. For LEP, having 20 microseconds time, the answer is clear. Nearly all chambers and counters are fast enough to be included in the trigger, if it is wanted. Even some already digitized data could be used. If the bunch to bunch time would be shorter (like at DORIS) some devices like slow drift chambers, would cause problems.

There is no need to use at the trigger level, all the detailed information available for each event. It would be anyway a serious problem to attempt to do so. Simple space problems limit the number of input lines to be used. Therefore the detector is divided into 'cells' which provide simple information to the trigger logic. So i.e. a whole group of shower counters may only send a few lines which inform if the sum of the deposited energy is higher than some prefixed thresholds. Groups of wires of proportional chambers may be used as single cells for track recognition. Obviously smaller cells will permit a more accurate job but the system will become increasingly complicated. The reasonable compromise seems to lie at present in the region of less than thousand cells for a standard detector.

Logic conditions (for tracks they have geometrical meanings) are tested on the signals coming from the cells. They can all be expressed as comparisons with preestablished masks or pattern. If any of these conditions, or a required combination of them is satisfied, than the event is stored for further analysis. In Figs. 5 and 6 some cell–structures are shown.

5. Fast Parallel Logic.

We consider as 'parallel logic' a system in which all operations are done simultaneously, to distinguish it from an equivalent 'sequential' system in which the same result is obtained performing many similar successive steps. The most complicated operation considered here is track recognition. A simple case is shown in Fig. 7 where it is searched for tracks in a Z–R system (along the beamline) in two cylindrical wire chambers (stripes read–out is assumed for Z) We need 50 'masks' to find out if a 'track' is present. However, using shift operations, as they will be described in the next chapter the number of required masks can be reduced to 5 or even to 1. The shift operations are done in sequence. Each mask represents a coincidence circuit which, in the case of more chambers could be quite complicated.

Another simple system is shown in Fig. 8 . Rudimental tracks are defined in two cylindrical chambers. In a second step it is tested if two such 'tracks' satisfy an azimuth condition. The result is a requirement of at least two, not adjacent 'tracks'. Five such pairs of chambers, each divided in 120 sectors, were used by the PLUTO group as fast 'pretrigger' for a subsequent slower trigger unit in which more chambers could be used to define better 'tracks'.

A reasonable system should use at least six chambers (or counter arrays) to define 'tracks'. One may ask if such a system can still be built as a 'parallel' logic, with simultaneous comparison with many thousand masks. The answer is simple today: such a system exists and is working successfully to select events in the CELLO detector (Fig.9) at PETRA (2). About thousand input lines (cells) are compared with about 5000 masks, each of them being a 'majority coincidence' requiring i.e. 5 out of 7 chambers to be 'on' (elimination of inefficiencies). Therefore each of the masks is equivalent a number of 'submasks'. Notice that the different masks must overlap to a certain extent in order to cover all possible track configurations. The comparison with all masks is done at the same time. An answer is obtained within a fraction of a microsecond. It is the fastest logic used up to now for such purpose and probably not the most expensive one. In addition, the masks are 'set' by a computer and can be changed whenever it is necessary. Such changes are useful, i.e. to establish the curvature limit to accept tracks (momentum cut) and adjust it to the background conditions. The circuits occupy about three racks and were built in collaboration with industry. Several other detectors (like TASSO) have parallel systems which work within one microsecond.

Another example of parallel logic is the trigger of the JADE detector (3). As it was shown in Fig.6, the number of 'cells' is smaller, making the circuitry much simpler. The masks are programmed as hardware and modifications are done exchanging some circuit boards. Field programmed hardware is much cheaper than computer controlled one. However, the cost of the fast trigger electronic is only a few percent of the cost of a detector and therefore the choice of hardware will depend mainly on the available manpower of each group.

A parallel trigger system can not be extended over certain limits given by its size, power consumption and cost. There are, however, situations (or physics reasons) which require additional background rejection. Apart from slower selection steps which are not discussed here, there is still a possibility to refine the cell- and mask-structure in systems working within 20 microseconds. This can be done sacrificing some speed, since 1 microsecond is not really required here. A possible technique for such systems is shown in the next chapter.

6. Sequential Logic.

The basic idea (already sketched in Fig. 7) consists in analysing only a part of the available cells of a detector in a so-called 'window' and then shifting the detector through this window (1,4). The shift operation can be performed with many different techniques, ranging from real 'shift registers' to mathematically equivalent software. Shift registers made of standard integrated circuit flip-flops can satisfy our speed requirement for a fast trigger.

An example of a system of four cylindrical chambers is shown in Fig.10. In the 'window' (right side) at each 'step', a parallel operation is performed, just as those described in the last chapter. The 'shifting' is done in a ring-shaped register (left side of the picture) which is conveniently placed as near as possible to the wire chamber electronics. From a set of pick-up points the information is transferred to the window, or even to several windows. To synchronize the rotational shift, all chambers must be divided in the same number of cells, a condition which may be sometimes difficult to satisfy. A sequential system like the one shown in Fig.10, was tested with the MADKA detector and two such systems (overlapping each other) are used in the PLUTO detector. The same principle was also used for the trigger of MARK II at SPEAR (4).

Using 120 cells per chamber, a complete rotation (including some overlap) can be performed in less than 20 microseconds, at a conservative speed of 100 nanoseconds per step. The number of masks, compared to the same logic made in parallel, is reduced in the ratio of the full detector to the window. However, some complication is added, in particular several delicate nanosecond timing problems. Several operations become particularly simple using shift registers. Track counting, coplanarity and angular correlations are a few examples. In addition, the register can be easily 'fed' sequentially with simulated data for check purposes and is also easily reaout. The recognized information (tracks, etc) can be used to speed-up further analysis steps.

There are very interesting sequential systems using other means to perform similar operations. We should mention here a device being built for TASSO called MONICA (5) which is very accurate in defining tracks but needs of the order of one millisecond. Another device is being prepared for the new detector ARGUS at DORIS, it is called 'Little Trackfinder' (6) and should work in 40 to 150 microseconds. These last system could perhaps be speeded up to be used within 20 microseconds.

7. Decision Logic.

Track finding devices are only one of the components of a complete trigger system. In some experiments a second such system is used in a R–Z projection. In addition, scintillation counters, shower counters, 'calorimeters', myon chambers and other devices may be included in the trigger. The first level of logic operations on these components is in general performed with commercial circuits, which are well known to all specialists and will not be discussed here.

Fig.11 shows a simplified diagram of the combination of four systems in a decision logic which again is controlled by a computer. Also here, the allowed configurations are like 'masks', but in this case without a geometric interpretation like it was in the case of tracks. To translate the trigger conditions into such masks special computer programs are needed (7). Not everybody agrees with this system and there are groups which prefer to set hardware switches for the same purposes. The position of these switches is read out and checked when data is read out.

Several levels of decision logic can be chained until the final YES/NO is obtained. The result is available within a few microseconds and care must be taken to reset all the system before the next bunch crossing.

8. Comments and conclusions.

The progress of the last years in the field of fast trigger systems is directly related to the improvements achieved in circuit integration. It started with the TTL–gates and shift registers working at more than 10 MHz and reached its present level with circuits like 'FPLA', the field programmable large logic arrays of AND/OR gates and their computer controlled partners, the 'RAM's, random access memories with compare facilities. All systems discussed here are based on such circuits.

Improvements are expected in the field of mass–storage of data and in biulding powerfull micro–logic systems. Perhaps one day magnetic tapes will stop to be the timing factor for triggers. More data would be first stored and than selected in special purpose devices working much faster than our present computers.

In conclusion we can say that within the 20 microseconds available at LEP for fast triggering the following systems could be used to select data:

- Parallel systems (1 microsecond) with
  about 1000 input channels and several thousand
  computer controlled masks.

- Sequential shift register systems (20 microseconds) with about 10 times better resolution (masks or cells) but more complicated.

- Decision logic systems with several levels controlled or set by computer.

There seems to be no need to use a sequence of two or more track recognizing systems within the first 20 microseconds (this is sometimes done on machines with shorter bunch to bunch time to reduce dead-time losses). One parallel or one sequential system, started at each bunch crossing, will be in general adequate. Triggers accepting events with only one or two tracks or accepting very 'soft' tracks and low energy events (like those happening in photon-photon physics), will need additional sophisticated selection steps (probably slower ones) before reaching acceptable rates.

Acknowledgments:

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Figure Captions

Fig. 1	Data flow in a storage ring experiment showing some rates.
Fig. 2	The cylindrical detector MADKA operated 1973 at ADONE to test trigger systems.
Fig. 3a	Some event configurations and their (observed) approximate rates.
Fig. 3b	Events which required particular care in the trigger.
Fig. 4	A typical detector configuration showing commonly used components.
Fig. 5	The cell structure of the MADKA detector with 4 x 120 wires and 8 scintillators.
Fig. 6	The cell structure of the JADE detector working at PETRA. Each group of wires (dots) is used as one cell but the walls between the cells are also used as cells for tracks crossing them. In addition information from outer counters (lead glass) is being used.
Fig. 7	Simple track recognition circuits showing the reductions achievable with slower sequential systems.
Fig. 8a	Direction-telescopes made of the cells of two cylindrical chambers. The coincidences obtained are fed into the angular correlation circuits shown below.
Fig. 8b	A complete set of correlation circuits operated as a trigger requirering at least two, not adjacent tracks.
Fig. 9a	Definition of the track-finding circuits used in the CELLO detector in the azimuth-radial view.
Fig. 9b	Definition of tracks in the R-Z view in CELLO.
Fig. 10	Principle of the shift register system for the case of four cylindrical wire chambers.
Fig. 11	A simplified diagramm of a two-steps decision-taking system as it is used for the PLUTO detector.

References:

Note: Detailed technical descriptions for trigger systems are rarely available. A visit to DESY and SLAC is perhaps unavoidable, for anyone planning new devices for electron positron storage rings.

(1) E.Iarocci and P.Waloschek, DESY–Report 72/13 (March 1972): "Hardware Logic for the Selection and Analysis of Events Observed in Charpak–Chamber and Counter Experiments".

(2) H.–J.Behrend et al., to be published in NIM: "The Fast Trackfinder for the CELLO–Experiment at DESY".

(3) E.Gademann and H.Krehbiel, JADE–Note Nr.30 (Dec.1978): "Trigger Scheme, Realization of T1" and M.Helm, H.Krehbiel and H.Riege, JADE–Note Nr.31 (Jan.1979): "Trigger T2 (JET–Chamber Fast Track Recognition)".

(4) H.Brafmann et al., SLAC–PUB–203 (October 1977): "Fast Track–Finding Trigger Processor for the SLAC/LBL MARK II Detector".

(5) P.Schild, H.–J.Stuckenberg and N.Wermes, DESY–Report80/11, (Febr.1980): "MONICA – An on–line Track Following Microprocessor in High Energy Physics Experiments"

(6) H.–D.Schulz, Internal Note DESY–F15 (1980): "Fundamentals and use of the Electronic Track Processor LITTLE TRACK FINDER". H.–J.Stuckenberg and H.Quehl, Internal Note DESY–F56(1980): "Functional Description of the ARGUS Track Processor"

(7) K.–H.Pape, Thesis, Hamburg University (1979): "RAM–Triggers fuer den Detektor PLUTO" (in German). Further data on the PLUTO trigger can be found in the "PLUTO–Handbuch" (in English).

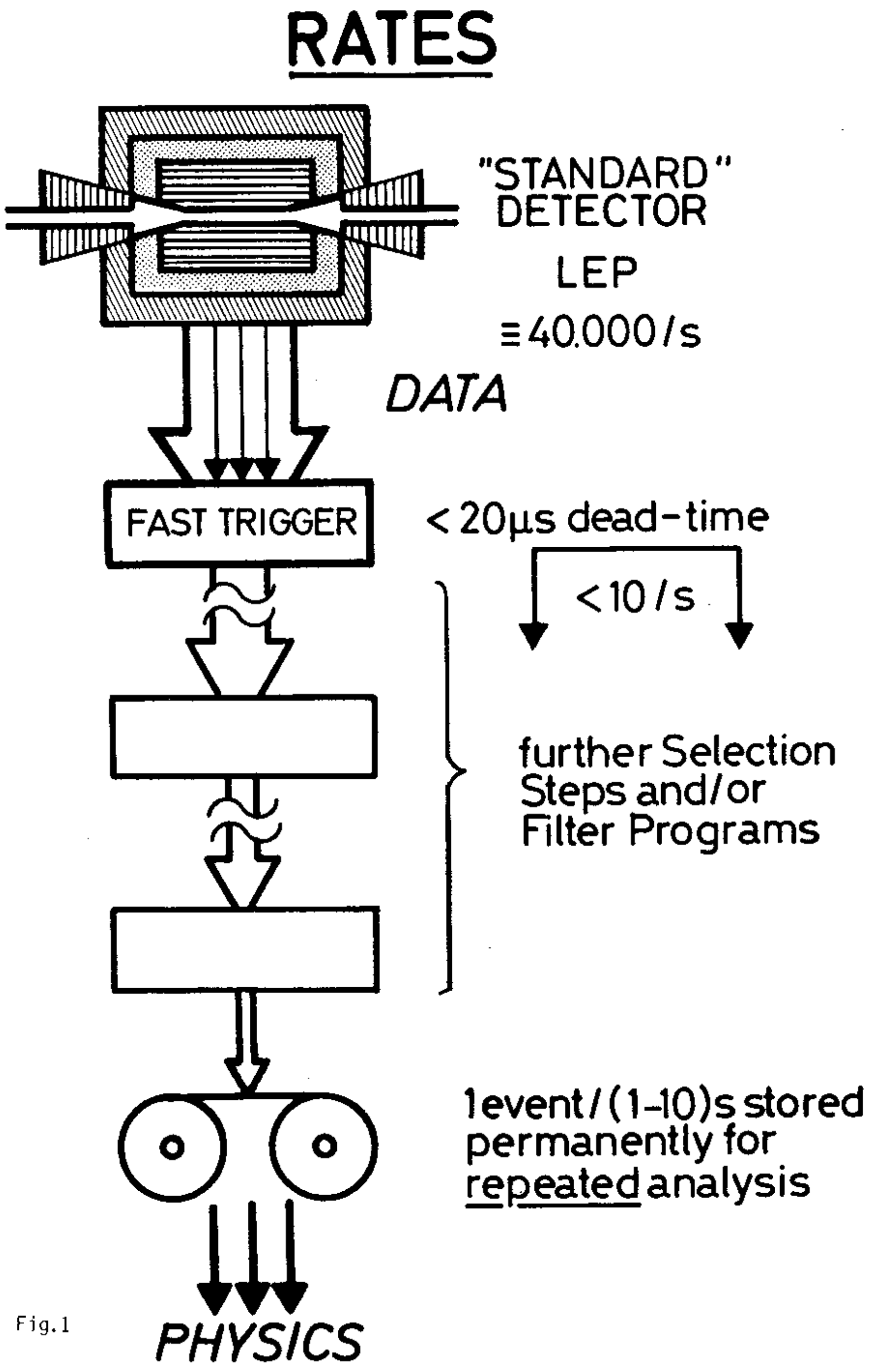

RATES
"STANDARD" DETECTOR
LEP
≡40.000/s
DATA
FAST TRIGGER
< 20µs dead-time
<10/s
further Selection Steps and/or Filter Programs
1event/(1-10)s stored permanently for repeated analysis
PHYSICS

Fig.1

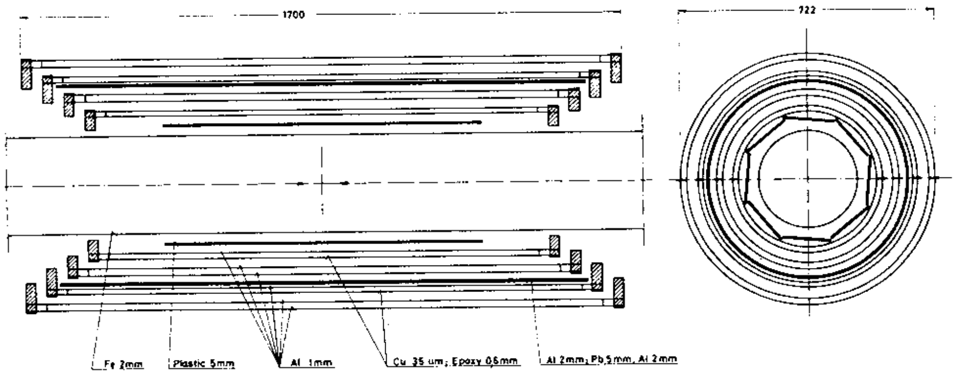

1700
722
Fe 2mm
Plastic 5mm
Al 1mm
Cu 35 um; Epoxy 0,6mm
Al 2mm; Pb 5mm, Al 2mm

Fig.2

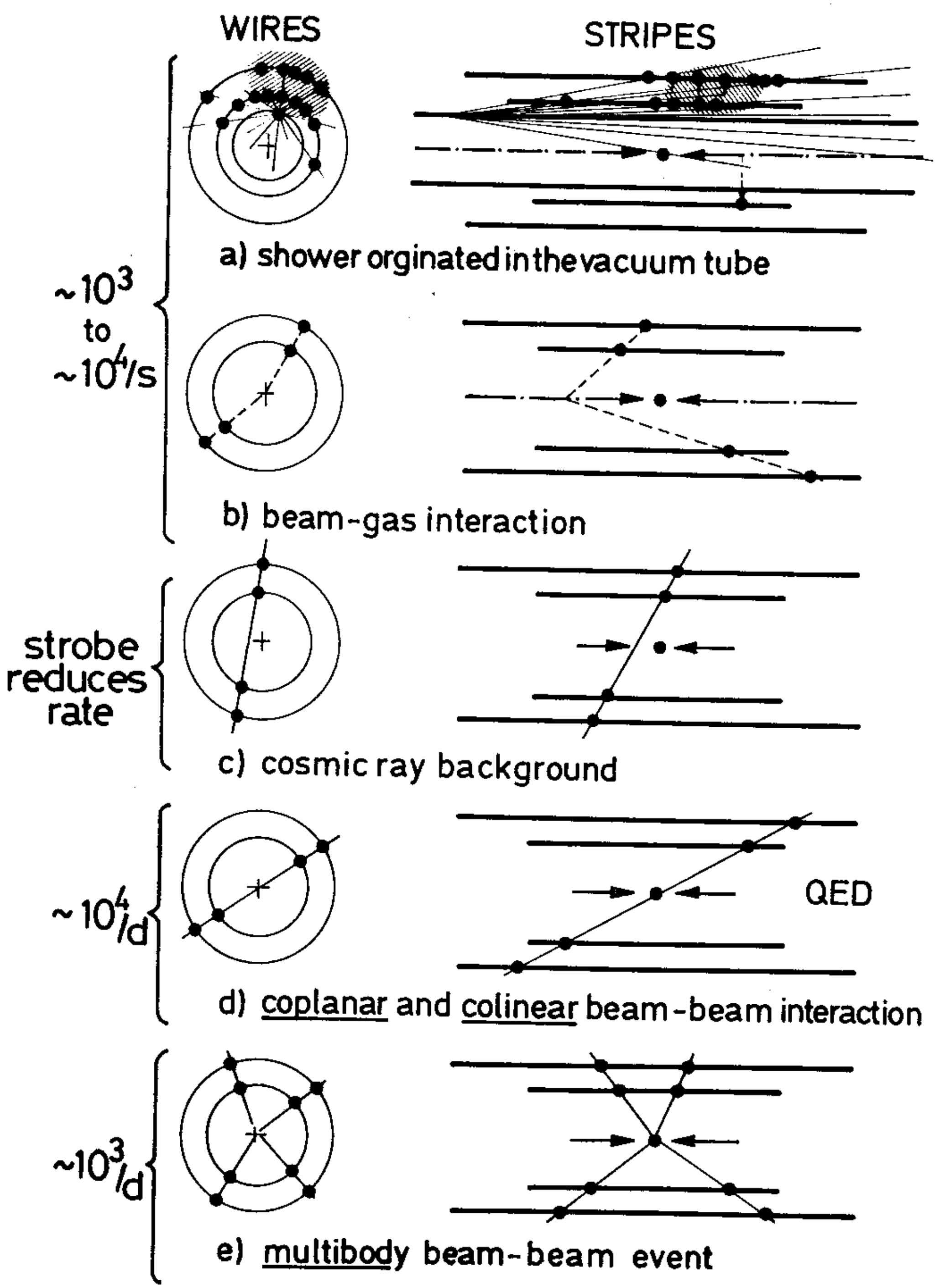
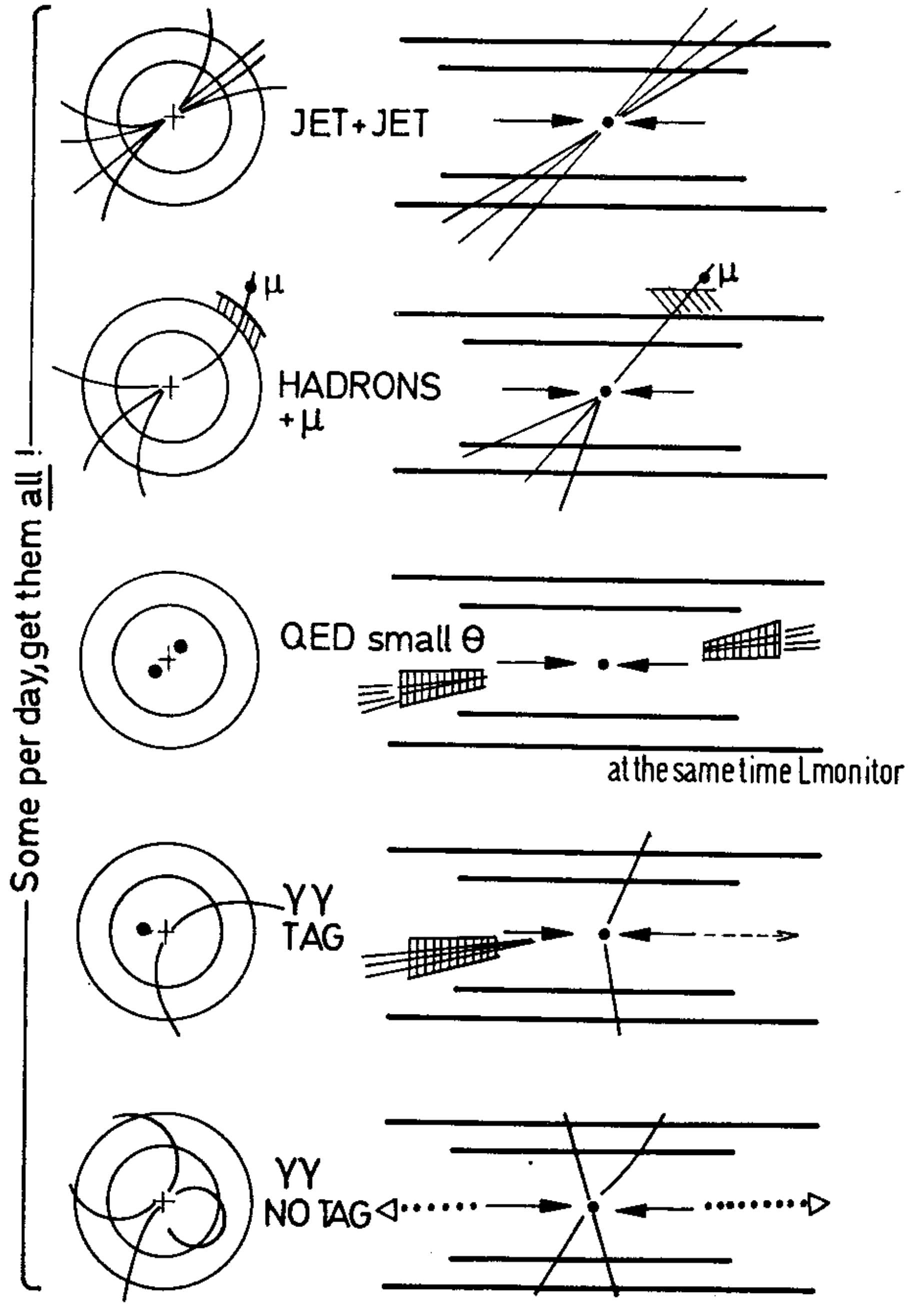


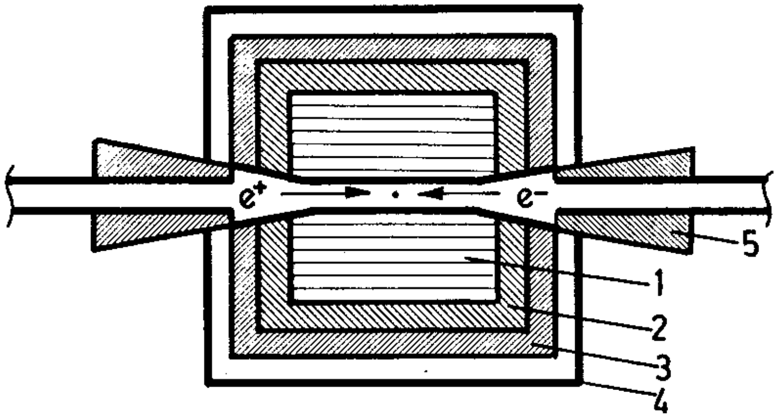
Fig.3a Some expected storage ring events and background



FLEXIBILITY for Combined Triggers is very important here.

Fig.3b

INPUT DATA "STANDARD DETECTOR"



1 Track Device —— Prop.-/Drift Chambers
2 Shower Counters —— Pb-glass-/Pb-Szint.-/ L.Argon Pb-Counters
3 Hadron Absorber —— Fe
4 Myon Chambers —— Drift Chambers
5 Forw.-/Backw. Counters - Pb.-glass/Pb-Sz.
+ obvious Magn. Field —— Coil

Fig.4

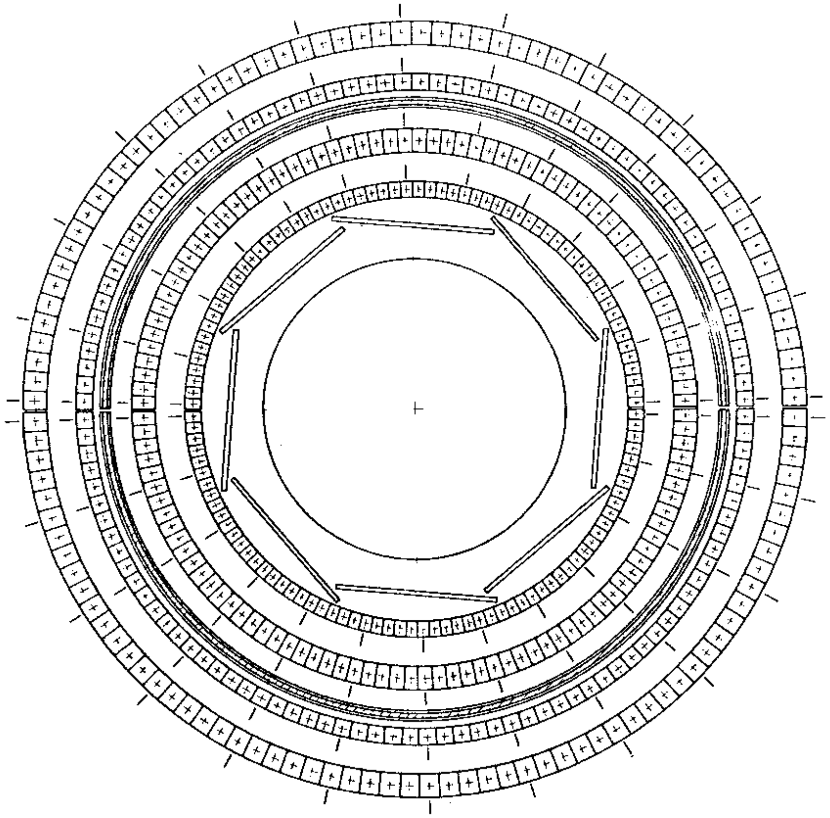


Fig.5

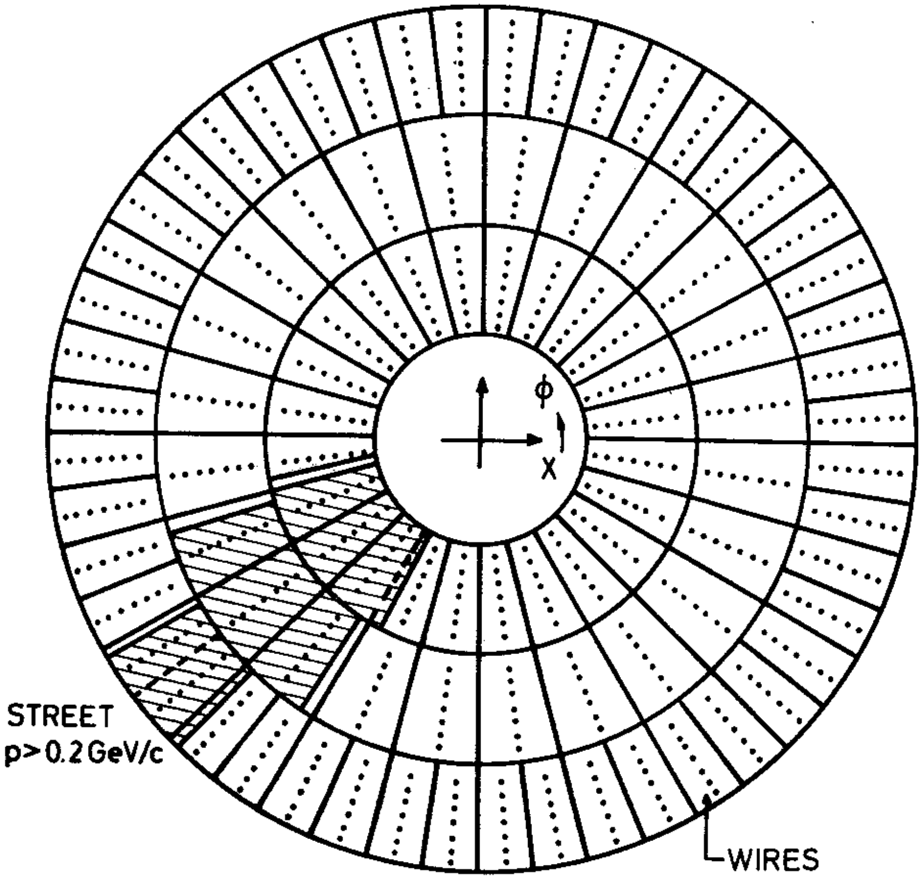
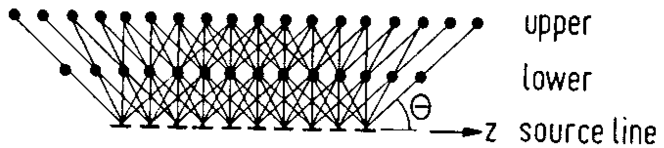
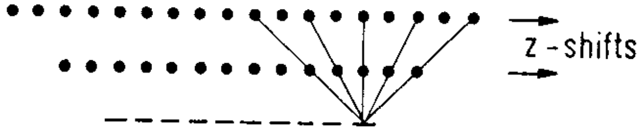


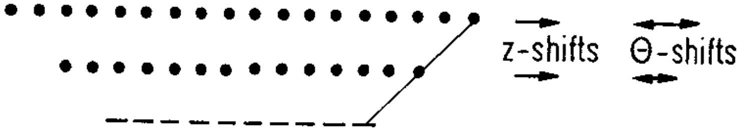
Fig.6



a) Bidimensional logic : 50 circuits



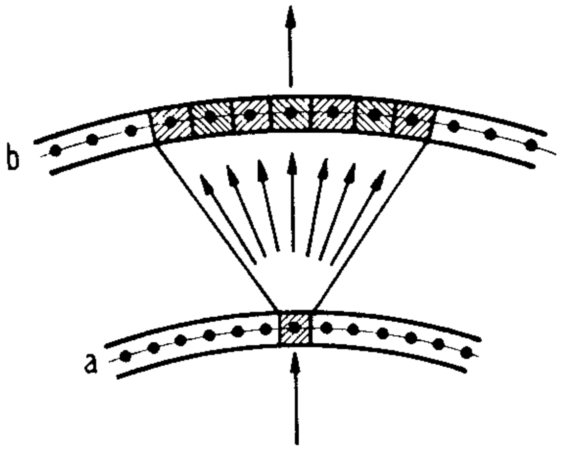
b) Undimensional logic : 5 circuits



c) Zero-dimensional logic: 1 circuit

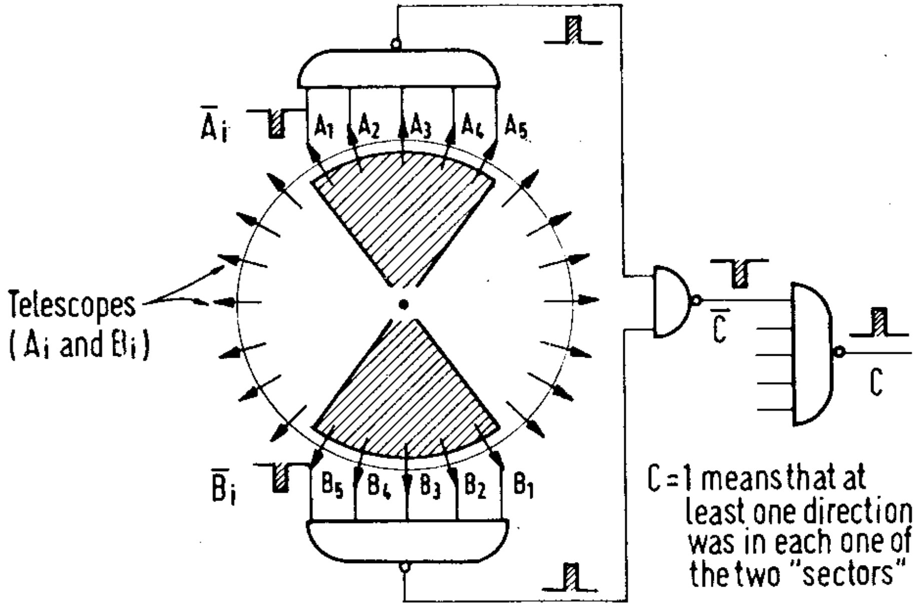
Parallel and sequential determination of Θ and z.
Each full line corresponds to a coincidence circuit.

Fig.7



telescope

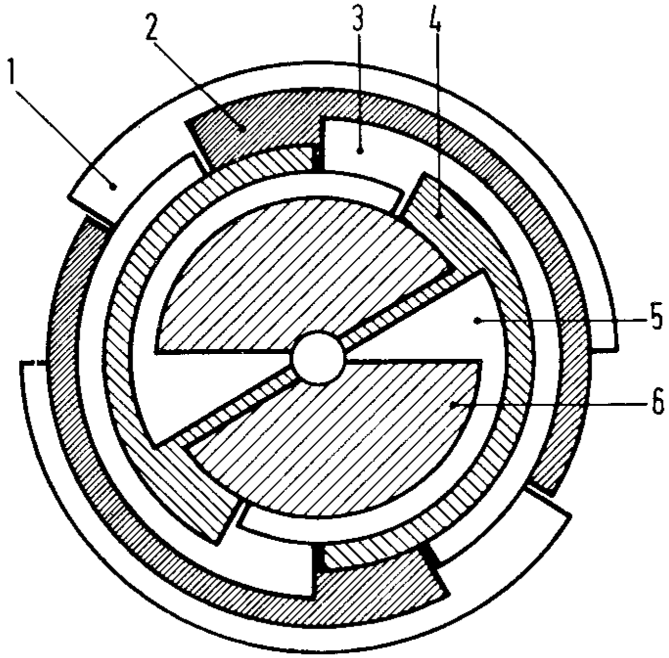
the acceptance of the telescopes can be externally controlled (7 intervals)



C = 1 means that at least one direction was in each one of the two "sectors"

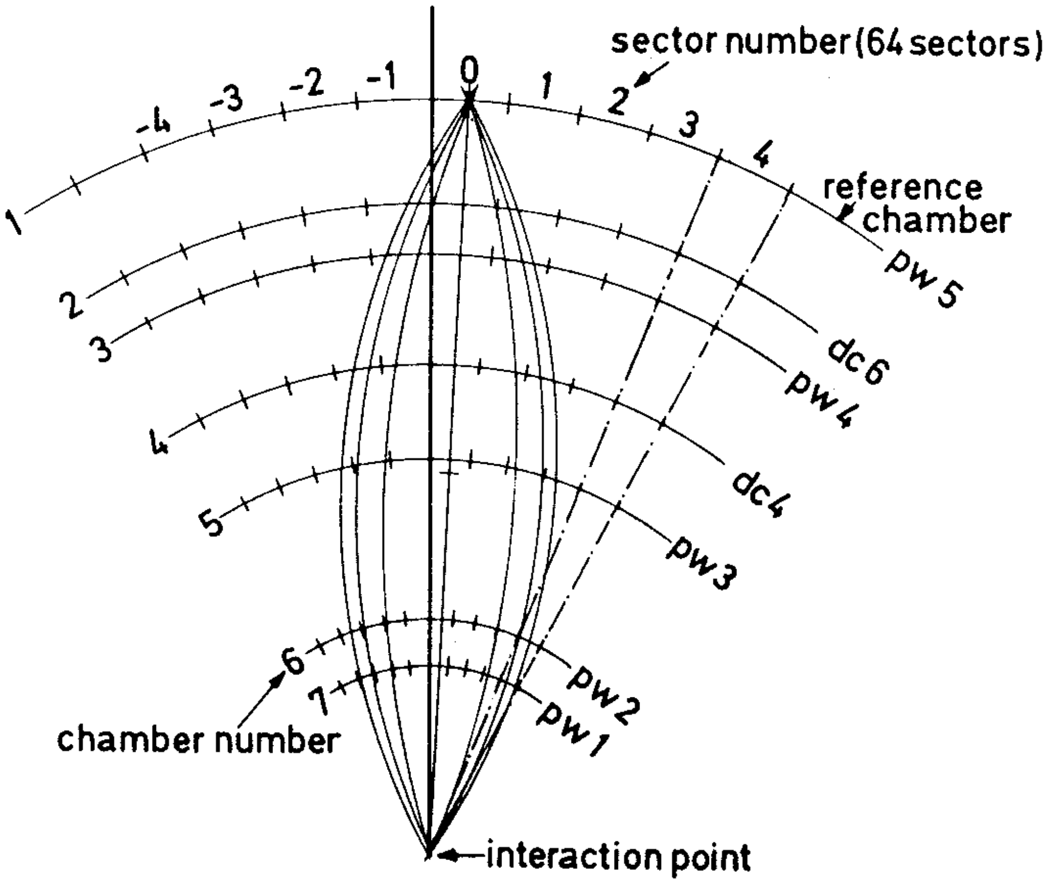
angular correlation

Fig.8a



Combination of 6 correlation circuits covering two 120°-sectors.

Fig.8b



track finding RΦ = All possible tracks going through the interaction point and reference sector 0 are stored in 12 RAMs (total number of masks : 57)

Fig. 9a

Sector arrangement in rz-geometry
(prop. chamber cathodes)
37 reference sectors, 67 masks per reference sector

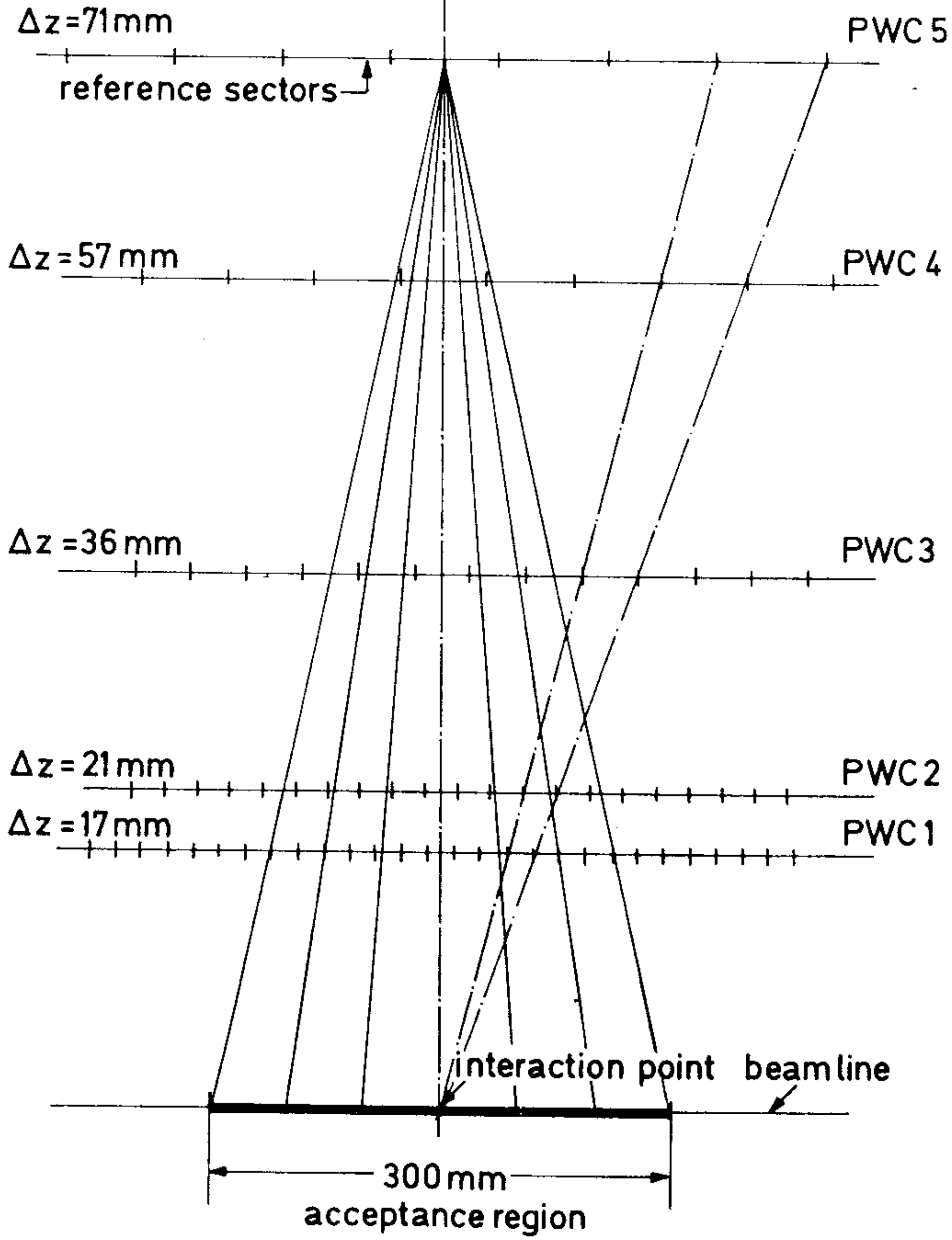


Fig. 9b

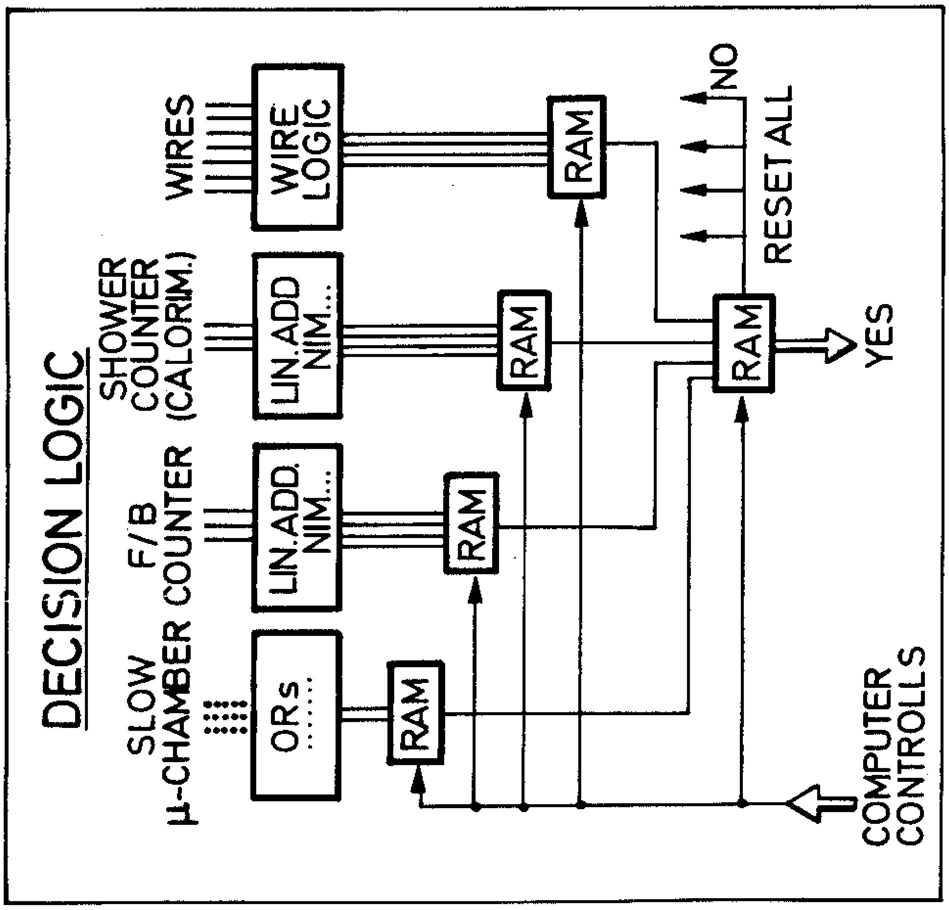

DECISION LOGIC
SLOW
µ-CHAMBER
F/B
COUNTER
SHOWER
COUNTER
(CALORIM.)
WIRES
ORs
LIN.ADD.
NIM...
LIN.ADD
NIM...
WIRE
LOGIC
RAM
RAM
RAM
RAM
RAM
NO
RESET ALL
YES
COMPUTER
CONTROLLS

Fig.11

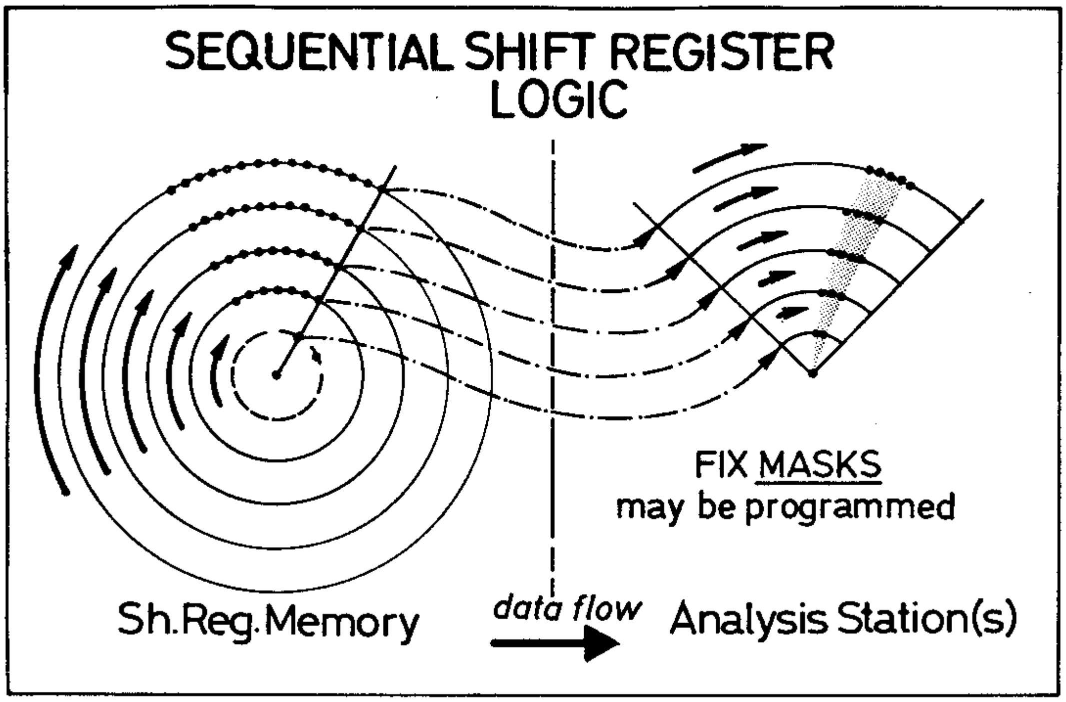

SEQUENTIAL SHIFT REGISTER
LOGIC
FIX MASKS
may be programmed
Sh.Reg.Memory
data flow
Analysis Station(s)

Fig.10