REMARKS ON FILM-LESS DETECTION SYSTEMS IN HIGH-ENERGY PHYSICS EXPERIMENTS

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Developments in film-less detection systems have been characterized by the following tendencies:

- to detect smaller and smaller cross-sections;
- to build larger and larger detectors, which leads eventually to an «almost-4π-geometry»;
- to measure more physical quantities per event;
- to catch more particles (photons, neutrons in addition to charged ones) emitted from the collision vertex (target);
- to increase the role of on-line computers as computers, rather than only as buffers.

I shall illustrate the above trends by discussing some features of the «missing-mass spectrometer», an instrument built at CERN specifically for the search for unstable mesons. A diagram of the system is given in Fig. 1. The reaction investigated is $\pi^- + P \rightarrow P + X^-$, where by $X^-$ we have denoted the unstable boson (or pionic resonance). The incident pion momenta used so far range from 3 to 13 GeV/c.

I would like to point out the difference between the systems used at Brookhaven and that of ours at CERN: while at BNL the emphasis is on the elastic processes which have high cross-section (million events per hour), our system has been designed for inelastic processes which have much lower cross-sections, and cannot possibly yield this many events purely from the point of view of the physics of the process. We have had, on the average, 3 triggers/burst (about 6,000 triggers/hour) and have recently increased the capacity of the system to 15 triggers/burst (30,000 triggers/hour).

MULTI-PARAMETER ANALYSIS IN COUNTER EXPERIMENTS

In the pre-spark-chamber era, counter experiments were typically two-parameter measurements (for example, one measures the number of counts versus angle). With the introduction of spark chambers, the number of parameters measured began to increase.

In film-less chamber and hodoscope techniques, the number of quantities measured in each count has become considerably larger. For example, our missing-mass spectrometer registers as much as 76 words of information (arrows in Fig. 1 b) about each event, at a rate of 3 to 15 triggers/hour.
events in a 250 msec burst. All information is stored on magnetic tape, and analysed off-line every 12 hours by a large computer; while 1 event/burst is completely computed by an on-line computer. This sampling is done in order that both the instrumentation and the physics aspects of the experiment be closely followed by the physicists.

DETECTION OF SMALLER AND SMALLER CROSS-SECTIONS

Fig. 2 shows the mass-spectrum of charged bosons from $M = 600$ through $2500$ MeV, as obtained by the missing-mass spectrometer.

We readily see the $\rho$-meson at $M = 760$ MeV, which is observed with the ratio signal-to-background of 3:1 (Fig. 3a). It is produced typically with $\sigma \approx 1000$ microbarns. Another broad peak seen at $M = 1300$ MeV is the $A_2$ meson, produced typically with $\sigma \approx 250$ microbarns.

In addition to these known resonances, we see three peaks: at masses $M = 962$, $1670$, and $2000$ MeV, produced with an order of magnitude smaller cross-section, $\sigma \approx 10.20$ microbarns. Only a relatively high-statistics experiment (in comparison with those obtained in bubble-chambers) could reveal a peak like the one at $962$ MeV, because in addition to having small $\sigma$, it appears on a background 8 to 10 times as large as the effect itself, as can be seen in Fig. 3b.

Further, there are two small bumps at $M = 1.08$ and $1.15$ GeV. If they are real, their cross-section is less than $10 \mu$ b. It is our aim to detect all such resonances characterized by $\sigma = 10 \mu$ b or less, and signal-to-background ratio of the order of 1:10. Consequently, our next measurements are to be **mega-event experiments**, designed to have $10^6$ events in histograms of mass-distribution; we expect that the first of these will take place in the first half of 1966. In bubble chambers, all discoveries of resonances have been made on the basis of, at most, thousands of events.

LARGE-SIZE DETECTORS

Large-size detectors have always been desirable from the point of view of the solid angles; however, they became possible or practical for the time-measurements only with the multiparameter analysis.

An example of a large counter used in our missing-mass spectrometer is seen in Fig. 4. Its area is $140 \times 75$ cm$^2$. Although the time difference in the light propagation from top to bottom (y-axis) is as much as 6 nsec, when we place in front of it a sonic spark-chamber of the same area we measure time-of-flight to an accuracy of $\pm 1.2$ nsec because the sonic signal gives the position at which the incident particle has hit the counter to an accuracy of $\pm 1$ mm. Then the computer calculates the light-path through the scintillator...
to the photomultiplier and subtracts the time of the light propagation in the counter from the measured time-of-flight.

(The curved light-guides are to equalize the light-path from any point along the x-axis and the photomultiplier: each of the 10 laminated light-guides is of the same length).

COVERAN

COVERAN is an abbreviation for «complete vertex analyser». By this, we understand a system of large magnets and various detectors (counters and chambers) that completely enclose the target so as to detect all particles that come from the collision vertex and to measure their angles and momenta.

COVERAN has not been built anywhere, so far; one can see that every film-less system is growing in the direction of COVERAN. For instance, the MM spectrometer system was originally designed to measure only the missing-mass of the recoil proton in the reaction \( \pi^+ + P \rightarrow P + X \). As we have obtained the peaks corresponding to the known bosons, we felt it necessary to measure also the number of the charged decay products of X; for this a matrix of 28 crossed counters was added to the system (M in Fig. 1). Recently, we added more spark chamber (VS in Fig. 1) to measure the angular distribution of the decay products, e.g. the pions from \( \bar{X} \rightarrow \bar{\pi} + \pi \), hoping to obtain information on the production mechanism and spin-parity of the states, at the same time as measuring their mass.

For the coming run we are introducing a gas Cerenkov counter into the beam to separate \( K^- \) from \( \pi^- \) induced reactions, i.e. to have two types of processes (strange and non-strange bosons) investigated simultaneously. Clearly, the next step is to put everything, including the target, into a wide-gap magnet, etc., etc.

RELAXING OF THE TRIGGER AND USING THE ON-LINE PRE-COMPUTING TO REJECT BAD EVENTS

Use of the on-line computer as buffer and/or sampling facility is far from exploiting their real potential. The strength of the fast on-line computer lies in the fact that it renders it possible to relax the trigger condition (relax the fast, nanosecond logic requirements) and let the computer do the rejection of unwanted events after a more
refined analysis has been done. The degree to which the trigger can be relaxed is determined by the maximum number of events/burst that the system can take.

There were two experiments in Europe, using sonic spark chambers that have done this type of post-trigger selection:

— the small angle elastic scattering experiment at CERN (Cocconi, Lillethun, Wetherell, and collaborators) using SDS 920 to check the time-counts coming from each microphone before the event is put onto the magnetic tape;

— the charge-exchange scattering experiment at Harwell (Manning, Lipkin, and collaborators) who used an analogue computer device to take the decision (during the time of propagation of sonic signal) if the event is a candidate for the desired scattering or not.

Pre-computing means also rejection of the data, and data rejection can lead to dangerous biases. Establishing the criterion for bias-free rejection is the most difficult task in an on-line experiment.

Fig. 5 shows our system for the coming experiment, presently being tested: the small (4K memory), fast (8 microsec) SDS 920 computer is envisaged to serve as the buffer, sampler, and pre-computer to the large CDC 6600 computer with which it is linked and of which we would use 20K memory. At this stage, the output from the 6600 will be brought back to the experimental area every hour or so (bicycle-on-line), but in the future we envisage an on-line output, via the same link.

MAGNETIC SPECTROMETER FOR INTERSECTING STORAGE RING

As our contribution to the discussion on the future experimental set-ups to be done with the storage ring at CERN, the shape of the magnets for particle spectrometers envisaged by us is shown in Fig. 6. To us, three points are essential for most of the detection systems associated with ISR: first, it has to cover large \( \Delta \varphi = 2\pi \); that is, \( \Delta \varphi = 2\pi \); second, the colliding region should be in the field-free region; third, there should be room for detectors before and after the magnet for the momentum analysis of the particles produced in the intersecting region.

The upper part of Fig. 6, the one-piece toroidal magnet, is mounted on a turntable. The magnet can rotate about the vertical axis from 20 to 160° to the beam direction. This magnet can be used only for the elastic scattering (both particles in one plane). For the inelastic processes the reaction plane is not defined and one has to have two half-toroid magnets, each being able to rotate about the vertical axis independently, as shown in the lower part of Fig. 6. (The detectors, which should enclose the colliding region and the magnet perimeter, are not shown).

Many of the above used or proposed ideas have resulted from discussion with my colleagues, Blieden, Freytag, Kienzle, Lefèbvres, Levrat, Martin, and other physicists who helped create our spectrometer system.

Fig. 6 - Proposed forms of magnets for particle spectrometer, to be used with the intersection storage ring at CERN (photographs of the models).