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The Porcupine

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THE PORCUPINE

Introduction

The most striking characteristic property in the collision of protons at high center-of-mass energies is the large multiplicity of secondary particles produced.¹ Theorists have called the process pionization, and it represents a kind of thermalization of the reaction products after the primary collision has taken place. These high-multiplicity events put to the experimenter a challenging problem of detection and data reduction. The present note has as its purpose to suggest a new 4π geometry concept for detecting the reaction products, which eases some of the problems of high-multiplicity events. The device could be used as a stand-alone detector in some experiments, but basically is conceived as a useful adjunct to a calorimeter type device. I call it the Porcupine for reasons soon to be apparent.

By high-multiplicity events, we mean average numbers of perhaps 10 to 20 final state particles, and (if the fluctuations are great) individual events with as many as 30 to 40, or even more. In a colliding beam apparatus, these particles emerge into the laboratory with a relatively uniform distribution in average polar angle (with respect to the beams), and laboratory energies ranging from a few hundred MeV for the pionization products to the so-called leading particles which may carry a

¹J.C. Sens, Rapporteur's talk, Oxford Conference, 1972.

large fraction of the incident beam energy. Most events seem to restrict strongly the transverse momentum given to any of the final state products, and an exponential dependence $e^{-(P_t/0.17)^2}$ is observed to hold for the strong interactions. The information noted thus far comes principally from inclusive spectra, and very little is known about the correlations among particles in a given event.

As long as we are interested only in the inclusive spectra, present methods of data acquisition and data processing will suffice. That era is drawing to a close, however, and one will soon wish a more global picture of the events. One manner of proceeding might be next to measure the two-particle correlation functions, then the three-particle functions, etc. and, by successively building up the moments of the distributions, reconstruct the average behavior of the collisions. This is an arduous task but one which requires relatively little innovation in method. A second approach is to record all particles in a given collision and obtain directly the information about multiplicities, angular distributions, momentum distributions and correlations. This means analyzing tens of particles in a 4π geometry. The second approach is the target of the many proposed "electronic bubble chamber" and calorimeter methods and will be the raison d'être of the Procupine.

Detector Concept

The Porcupine looks like its namesake. It consists of about 47,000 proportional wire counters with their active volumes aligned so that the multiplying wire electrodes all point at the interaction region. Each counter thereby becomes its own charged particle detector, and the large total number of elements insures (to first order at least) that each reaction product will trigger a unique detector. One gets a complete spatial picture of each event with no further analysis or reconstruction necessary! No information is known at this point about the individual charged particle momenta or the neutral particle multiplicities. This, of course, is the reason for combining the Porcupine with some sort of segmented calorimeter. More specifically, the Impactometer of Willis² seems to be an appropriate device for the purpose. We therefore will tacitly assume the rough features of that device in discussing the present one.

The idea of having one detector element per reaction product is not a particularly earth-shaking one, but in recent years it has been in disfavor as it has been uneconomical relative to what one might call a "square root" device. A square root device is any method by which a two-dimensional space with a unit cell size $\delta x \cdot \delta y$ is specified by the correlation of two numbers n_x and n_y , each of which measures only one of the coordinates of the space--hodoscopes and spark

²W.J. Willis, "The Impactometer," CRISP

chambers are typical examples. A hodoscope with 10 elements in x and 10 in y can replace a 100-element array of individual detector elements. In general, for a large detector with fine granularity, the final cost is enormously reduced by using square root devices (and thereby square root cost). Except for ambiguities ...

By this we mean, of course, the problem of correlating the elements of the x-measuring device with those of the y-measuring one for events with more than one particle detected. The most common approach is to use several coordinates which are linearly independent combinations of the desired ones, and to reduce the data to a set of mutually compatible choices for the real trajectories. When detector inefficiencies are taken into account, the amount of redundancy rises and one continues to gain significantly only in detectors with single coordinate granularities in the neighborhood of 100 or so; i.e., two-dimensional grids with on the order of 10,000 elements.

This is still not the complete picture because the square root devices must submit to an algorithm for eliminating ambiguity and establishing correlation. For spark chambers, this is called the "N-track algorithm," and in general the amount of time that a computer needs to solve the associated problem varies as a factorial function of the track number N. Present computers and track-finding algorithms take times on the order of seconds to find track numbers on the order of 10. A crude graph shows the cost of detecting N tracks and the

cost of extracting the tracks in a computer for a typical experiment.

Figure 1: A "SQUARE ROOT DETECTOR" EXPERIMENT COST CURVE

The particular values are less important than the overall behavior. It is clear that the cost of extracting information from a given detector has a very inelastic upper cost limit.

One way to bypass the straightforward limit is to use many regions, each with square root devices, but with enough regions to keep the average regional multiplicity under control. Clearly, the detector cost will rise and the analysis cost will fall with this intermediate approach. Such an approach would probably be practical for events in which the particles did not cluster in solid angle. Unfortunately, this clustering is just the property we most expect to see as energies rise and "jets" of particles make their appearance in the forward and backward directions (and perhaps at relatively large angles

to the beam as well). We are therefore forced to consider devices with one element per particle. The Porcupine is one example. The cost curves for such a device might look as shown below.

Figure 2: A PORCUPINE DETECTOR EXPERIMENT COST CURVE

The principal gain is in reducing the factorial cost of computation to more like a linear function as N increases. This gain is the result, as stated before, of avoiding the N -track correlation algorithm. Instead, one merely applies a linear classification routine to assign the unambiguous raw data to meaningful accumulation categories.

A second reason for considering the explicit Porcupine approach to the unit detector method is the problem of background. Ideally, one would like to be 100 percent efficient for detecting particles from the interaction point, and immune to all others. In this way, general room backgrounds, beam-wall collisions, and beam-gas collisions not in the

immediate interaction region would be ignored, while particles from the beam-beam collisions would be detected with high efficiency. That this is not exactly possible is apparent when one notes that the interaction region is at least 10 cm long for useful luminosities and perhaps 1 cm in diameter. Thus it is a fat line-source rather than a point-source of real events.

Even though the ideal detector is not possible, one can at least make a favorable detector. By suitably choosing the aspect ratio of diameter to length of the Porcupine elements, and by linearly OR-ing the signals of properly chosen groups of elements, the device can be made insensitive to minimum ionizing radiation from all directions except a narrow cone emanating from the vicinity of the source. General room background then will not trigger the device at all, since it will not deposit sufficient energy in any one element. A prime reason, therefore, for the specific Porcupine approach is its strong selectivity in solid angle.

A second very important background consideration is the speed of the detector. Here the Porcupine is actually inferior to another possible approach. One might consider using scintillation or Cerenkov counter elements in the same basic configuration (unit detectors with restricted solid angle acceptance). This approach is very attractive, but the factor of 20 or so that one might gain in bandwidth is accompanied by an increase in unit cost of a comparable amount.

Since one is talking about element numbers on the order of 10,000 to 50,000, an increase in unit cost from \$3 to, say, \$30 raises the total cost of the detector from about \$150 K to \$1.5 M. Until one has exhausted the physics which can be done at luminosities around 10^{30} to 10^{31} , it seems that the less expensive proportional counter approach is most attractive.

Given this background as a reason for proceeding along the lines of a unit-detector proportional counter array, we can write down some of the details which such a device might encompass in a practical design.

Geometry of the Array

Each detector element is a right, regular hexagonal pyramid with the multiplying wire as its axis and a set of six surrounding wires at negative high voltage to define the ion collection volume. The apex half-angle is determined by the solid angle subtended by the element and might plausibly be about 0.01 radian. If the entire 4π steradians are to be properly covered, about 47,000 counter elements are required. The elementary counter is shown in Figure 3 below.

Figure 3: BASIC DETECTOR ELEMENT OF THE PORCUPINE

Any plane can be tessellated by a field of hexagons; therefore, we define as a detector module an equilateral triangle containing 456 elementary hexagonal counters, and as a sub-assembly a set of four equilateral triangle modules. Examples of a module and of a sub-assembly are shown in Figure 4 (see next page). Finally, 18 sub-assemblies are combined into an icosahedron about the interaction region. The beams enter and exit through the two missing faces of the polygon.

Figure 4: PORCUPINE MODULES AND SUB-ASSEMBLY, END-ON VIEW

If one considers carefully the details of a sub-assembly, it will be noted that Module 1 must be different than Modules 2, 3 and 4. The differences are, however, slight. One might imagine mechanical supports at the corners of Module 1 supplanting the counters at those points. This would cause loss of about 0.2 percent of the solid angle. The missing sub-assemblies in the region of the beam pipes would cause an additional loss of 10 percent of the total 4π solid angle ... if one were to let it go at that. Actually, since the solid angle close to the beam direction is a very interesting and important piece of real estate, it is worthwhile to take special measures with it. Accordingly, a better array is gotten by placing a set of four sub-assemblies downstream and

upstream of the missing beam sub-assemblies which then subtend the same solid angle region, but with an increase by a factor of 2 in angular resolution. The practical detector therefore would take the form of an icosahedron of sub-assemblies (18 in number) about the interaction region, and two sets of four sub-assemblies placed about twice as far upstream and downstream of the interaction region. These two sets would then subtend the same solid angle as the missing pieces of the original polygon. Clearly, the process could be repeated one more time by leaving out the central sub-assembly of the upstream and downstream groups and covering their solid angle in turn with two more groups of four sub-assemblies, placed even further away. Unfortunately, this scheme begins to become as complicated to use as it is to describe. It would require a total of 32 sub-assemblies (57 K counter elements) as opposed to 26 sub-assemblies (47 K counter elements) for the favored intermediate array. For a simple icosahedron 20 sub-assemblies are necessary (36 K counter elements).

To give an idea of the resolving power, note that two particles of 30 GeV/c would need a relative transverse momentum of only 0.3 GeV/c to be separated by one full cell width in the intermediate array. If present indications from the ISR hold at higher energies, the preferred final states will tend to have many particles of lower energy with consequent increased separation among counter elements.

At large angles to the beam where jet structure will be most model-sensitive, the resolution is extremely good and particle pairs moving out with as much as 3 GeV/c will require only 60 MeV/c relative transverse momentum to be separated spatially. These large angle jet resolution characteristics make the Porcupine the instrument of choice in studying correlation phenomena in the pp inelastic collisions.

Electronic Details

Prior to the existence of cheap and reliable solid state electronics the Porcupine concept would have been thought certified madness. Currently, however, experimental groups operating arrays of thousands of proportional wires report extreme stability and reliability of operation. To contemplate arrays of tens of thousands of elements is to worry more about cost than about reliability. Here, dramatic progress has been made, even since the early large proportional counter arrays were developed. These systems typically cost in the neighborhood of \$10 per wire with an ability to detect as little as one ion pair from the originating event. The Porcupine elements will need far less electronic capability as one expects to have on the order of 2000 ion pairs per traversal, and a triggering threshold of perhaps 1000. This enormous increase in signal combined with the much easier geometry of the counter itself should limit the electronics cost to something less than \$3 per counter for amplifier, delay, memory element, and fast fan-in. Thus, a cost estimate for the electronics of around \$150 K is reasonable.

The electronic configuration most likely to be useful is shown in Figure 5 (next page). The amplifier should be capable of producing a pulse adequate to trigger the delay element for an input charge of 1000 ion pairs. The delay element should be capable of holding for some nominal time, then triggering the gated memory element. The timing of the

Figure 5: ELECTRONIC BLOCK DIAGRAM

delay should be controlled by production tolerances on components and should not require "tweaking." This is vital in a system this large. The memory element should have a gated output for purposes of multiplexing. The linear OR should preserve the linear characteristic of the original charge collected by the chosen group of amplifiers, and should produce an output of suitable magnitude. All linear elements must be controlled in gain by production tolerances on components rather than by adjustment for the reasons stated above. The system should be packaged in a modular manner for easy replacement of parts.

The packaging question suggests another basic problem to be dealt with; namely, the radiation damage to the solid state

components by the ambient environment. If methods are introduced to substantially reduce the time-averaged radiation levels from those encountered at the ISR, one might consider mounting the electronics on the detectors, and so save a lot of wire. It is more likely, however, that the electronics will have to be shielded from the environment; it may be necessary to have long cable runs carrying the primary signals from the proportional wires. With the 1000 ion pair threshold for the initiating burst and good gas multiplication this should be feasible. Parallel geometry multiwire flat cable is the most likely candidate for carrying the signals here and there. More study of this question is clearly necessary.

Mechanical Details

Each module of 456 counters will be built as a unit. The end pieces will be ordinary, 60-mil, glass epoxy printed circuit board with the proper array of holes for high voltage and counting electrodes. The wires can be secured in plated-through holes by solder and the appropriate patterns of inter-connections made by standard PC techniques. There will be a few mechanical supports between end plates, but the principal rigidity would come through application of a sufficient gas overpressure to properly stress the wires and provide a rigid package (much like an inflated air mattress). It is hoped that the two end plates, combined with inter-modular seams and sub-assembly side sindows, can provide a properly isolated gas volume. If leaks are a problem, the entire detector could be placed in a plastic bag of the same gas as used in the chambers. This is messy but feasible if the desired solution is not practical. Note that the absence of solid walls inside the counters makes the problem of gas circulation a trivial one.

The transmission cables should be soldered or clamped to the outer surface of the PC board with the land arranged for convenience and reliability; the proposed density of one-half a signal wire per cm^2 should present no serious packing problem. The means of bundling and transporting the mass of cables could be a major headache without

use of cunning and foresight. Again, this problem needs more study but is not basically hard.

The wires will probably have to be threaded by hand, so some thought needs to be given about jigs and fixtures to simplify the labor and to control alignment. Hard-drawn copper should most likely be used for the cathode and gold-plated tungsten for the anode. Present technology with proportional chambers should be able to point the way on many of these questions. The best gas to use will have to be decided by the results of tests on prototypes.

Conclusion

The Porcupine detector has been introduced, and some arguments for its feasibility have been presented. Whether it will ever be used depends upon its competitiveness with other systems, either conventional or novel. If the physics continues to favor high multiplicities and large fluctuations combined with the clustering effect we call jets, a concept along unit-detector lines will surely be needed, and perhaps it will be quite close to the system outlined here.