

CERN-EP/80-168
8 September 1980

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CM-P00062325

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FOR THE ISR AXIAL FIELD SPECTROMETER

BNL-CERN-Copenhagen-Lund-Rutherford-Tel Aviv Collaboration

presented by C.W. Fabjan

Invited talk at the
International Conference on High-Energy Physics,
Madison, Wisc., USA, 17-23 July 1980

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ABSTRACT

Drift-time information from the central detector and energy deposit from a surrounding hadron calorimeter are used for complex trigger and on-line selection procedures. High- p_T ($p_T \gtrsim 5$ GeV/c) charged particles and special event topologies can be selected with high efficiency. The hardware approach and performance is discussed.

INTRODUCTION

Recently the Axial Field Spectrometer (AFS) was brought into operation at the CERN ISR. It is at present being exploited by the BNL-CERN-Copenhagen-Lund-Rutherford-Tel Aviv Collaboration ¹ in a broad physics programme to investigate the hard scattering of nucleon constituents. Such events occur with cross-sections in the μb to nb range, or even smaller, may be produced by different incident particles (pp , $p\bar{p}$, αp , $\alpha\alpha$ collisions), frequently in the environment of very high interaction rates (present luminosity is typically $> 2 \times 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$, which corresponds to a particle flux of $> 10^7 \text{ s}^{-1}$ into a 4π detector). Central to efficient study of these relatively "rare" events are trigger and filter schemes, matched in processing power to the primary interaction rate and of sufficient discrimination to permit practical off-line analysis methods. Acceptance criteria, based for example on the momentum of a charged track, are typical for high- p_T studies; energy deposit in a hadron calorimeter provides information on event topologies, e.g. on "jets". Information combined from tracking devices, calorimeters and particle identifiers suggests sensitive detection of or searches for states containing heavy quarks. Their production rates at hadron machines are enormous: at the ISR about 10^9 $c\bar{c}$ systems and 10^6 $b\bar{b}$ systems are being produced daily!

HIGH- p_T SINGLE PARTICLE TRIGGER

Charged particles are momentum-analysed in a "pictorial" drift chamber ² (cylinder divided into 4° cells with up to 42 space points per track) immersed in a 0.5 T magnetic field, coaxial with the ISR beams. The poles of the magnet were specially shaped for completely unobstructed acceptance over the full azimuth in a polar range of $0 < \theta < 15^\circ$, $40^\circ < \theta < 140^\circ$, $165^\circ < \theta < 180^\circ$. A three-layer Čerenkov arm (thresholds at $\gamma = 4, 10, 20$), interleaved with proportional chambers (PCs) provide particle identification over 1 sr. Liquid-

argon shower detectors are installed, but will be replaced by an 8 sr hadron calorimeter at present under construction. The physics programme for 1980 emphasizes two topics: the study of events containing a high- p_T ($p_T > 5$ GeV) π^0 or direct photon, using the liquid-argon shower counters, and secondly the inclusive spectra of identified high p_T charged particles and their associated event topology. Of particular interest is the p_T range $5 \text{ GeV}/c \lesssim p_T \lesssim 12 \text{ GeV}/c$, requiring highly selective, yet highly efficient triggering and filtering methods. This is accomplished with the *High p_T Single Particle Trigger*, a sequence of increasingly more selective conditions as schematically summarized in Table I. A series of pretriggers achieves a reduction factor of a few hundred, reducing the rates of candidate events to a few kHz. At this rate it becomes possible to address the heart of the trigger chain, ESOP^{3,4}. ESOP is a microprogrammable processor for high-speed data treatment. It is built with TTL logic in NIM/CAMAC mechanics, and consists of dedicated autonomous sub-units which operate concurrently under control of a common command module. This configuration permits one 48-bit microcoded instruction to be executed every 125 ns. Its high degree of parallelism gives an over-all speed of one order of magnitude faster than typical mini-computers.

Table I High- p_T particle trigger (typically: $L = 2 \times 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$)

DETECTOR	TRIGGER	RATE	DECISION TIME
Forward scint. hodoscope	Interaction trigger	$6 \times 10^5 \text{ s}^{-1}$	10 ns (1)
PC groups barrel hodoscope	Single particle pretrigger (SPT)	$6 \times 10^4 \text{ s}^{-1}$	60 ns (2)
Wire hits in PC1 and PC2	RAM threshold, p_T from 2 to 5 GeV	$\sim 10^4 \text{ s}^{-1}$	700 ns (3)
Pulse height on radial groups of 12 d.c. wires	d.c. fast or processor	$\sim 2 \times 10^3 \text{ s}^{-1}$	800 ns (4)
Drift time measurement on 16 wires/sector	ESOP program. processor p_T : 2.5 to 5 GeV	few s^{-1}	200-300 μs

Comments

- (1) Scintillators provide "unbiased" detection and time of interaction
- (2) Hardwired coincidence between barrel scintillators and wire groups from two PC planes. "Roads" accept particles with $p > 1 \text{ GeV}/c$.
- (3) Individual wire hits in PCs are compared with map of possible hit combinations for a high- p_T particle. Hit combinations are stored in a computer-loadable memory and allow change of threshold.
- (4) Analogue signals from radial groups of wires in a sector are summed; discriminator logic checks for track candidates.

Detectors external to the drift chamber (PCs through RAM logic, calorimeter modules) point to sectors in the drift chamber containing a high- p_T track candidate. Tracks crossing from one 4° sector into the neighbouring must be allowed, as well as up to two tracks/sector. For each sector the drift time from four, equally spaced groups of wires are read out. Each group consists of four wires, on which several checks are executed (solution of right-left ambiguity, t_0 corrections, max. drift time, etc.) and then the drift times are combined into track segments, represented by master points. Track finding then proceeds on the totality of master points from each pair of sectors; a sagitta is computed for each track and compared with a preset cut-off value.

The global efficiency of this trigger chain, which includes effects of the extended source of interactions, edge effects and misalignments of detectors, is found to be very high: at a threshold setting of e.g. 5 GeV/c we find a 95% acceptance for the SPT condition, $\sim 80\%$ for the RAM trigger and 65% for the full processing chain, which increases to 80% at $p_T = 6$ GeV/c. Figure 1 is indicative of the performance achieved so far. It shows the p_T spectrum of all charged particles; the data were taken at the indicated thresholds and subsequently processed through the off-line analysis chain. The data which are corrected only for the previously mentioned geometrical acceptance, are normalized to the "expected" spectrum, defined as $\text{Expected} = 3.3 \times \text{Measured } \pi^0$ spectrum. The quality of the trigger events is further emphasized by the fact that even at the highest thresholds of 5 GeV/c the purity of the sample is very high: almost 10% of all analysed events contain a particle with $p_T \geq 5$ GeV/c, as evaluated by the full off-line programme. The remaining events have resulted in a valid trigger principally for two reasons: Due to the reduced resolution of the momentum measurement at the trigger stage

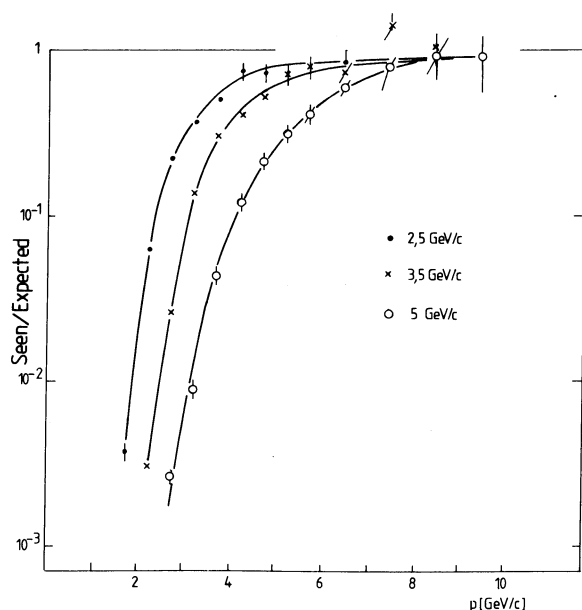


Fig. 1

The measured p_T spectrum of charged particles, normalized to 3.3 times the π^0 flux, taken with three different trigger thresholds. In the p_T range from 5 GeV/c to 10 GeV/c the particle flux drops by approximately four orders of magnitude. Only one particle in 10^9 will have a $p_T \geq 10$ GeV/c.

a track below threshold may simulate a larger p_T track. This is a dominant effect as lower p_T particles are very much more abundant ($E d^3\sigma/dp^3 \sim p_T^{-8}$). These tracks are recognized off-line, where the complete drift chamber information provides improved momentum resolution. A second important source of false triggers is caused by two low momentum tracks, which overlap in a sector and simulate a high p_T particle at the ESOP decision stage.

THE CALORIMETER TRIGGER

The hadron calorimeter, at present under construction, uses uranium plates as absorber, sampled with 2.5 mm scintillator plates, which are read out by 2 mm thick wavelength shifters ⁵. High granularity has been achieved by reading cells of 20×20 cm² cross-section with two wavelength shifters for each of the two longitudinal subdivisions (the first 6 radiation lengths and the subsequent 3.7 absorption lengths). The calorimeter modules surround the drift chamber in a box-like structure, such that four identical "walls" provide 2π azimuthal coverage. Energy leaking through the four corners created by the walls is measured in copper-scintillator calorimeters. The completed calorimeter will have 3200 individual signal channels. For trigger purposes, however, the dynode signals of the electromagnetic (e.m.) and hadronic segments at constant azimuth ("rows") are summed, resulting in 48 primary e.m. signals and 48 plus 4 (from Cu modules) hadronic signals. These 100 signals are transmitted via air core cable ($v = 0.95c$) to the counting room for further processing. As indicated in Fig. 2, the hadronic sums of adjacent rows are combined, with an overlap of one. Triggering on energy deposit in such a narrow slice will preferentially select configurations, where most of the energy is given to a single hadron. Likewise, six rows of cells ($\Delta\Omega \sim 1$ sr) are combined to "jet sums" to achieve sensitivity for topologies expected to be characteristic of "jet" structure. Again,

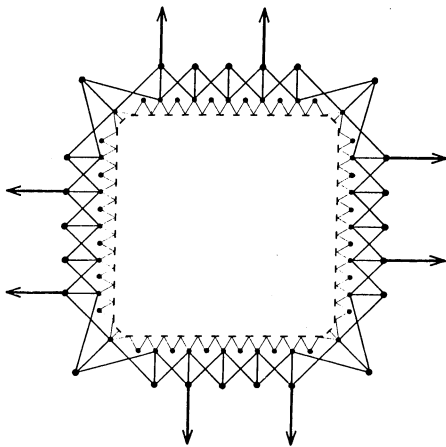


Fig. 2

Schematic diagram of the calorimeter sums. A small line segment on the inner square symbolizes a "row" of calorimeter cells. The lines joining two rows represent a "Single Particle" sum, whereas the next level of summing over six rows represents the spatial extension of "jets".

geometrical overlap of 67% in the jet sums minimizes edge effects in the azimuthal trigger efficiency. The energy sums provide also a measure of the total deposited energy, E_{tot} , which is used as a pre-trigger and strobe for ADCs. A total of 123 fast, linear sums are generated in this way (48 e.m. single particle (E.M.), 48 hadronic single particle (S.P.), 24 jet sums (J), E_{tot} (E), E_{tot} e.m. ($E_{\text{e.m.}}$), $P_{\text{T,tot}}$ (P_{T})). These sums are interrogated by multilevel discriminators (3 levels for E.M., 5 S.P., 4 J, 6 E, 4 $E_{\text{e.m.}}$, 3 P_{T}) resulting in 493 signals. Subsequently, the definition of the e.m. single particle trigger is refined by requiring a spatial coincidence of an E.M. signal with a consistent value of an S.P. All the information thus obtained is "multiplicity"-encoded, and transmitted in encoded form onto 33 signal lines. Other detectors (PCs, DCs, etc.) may also provide information to be correlated with the calorimeter signals for which 17 encoded lines are provided. Logic decisions on the information pattern present on these 50 signal lines are carried out by an array of high-speed logic units. Each distinct trigger pattern, represented by a unique signal pattern on the 50 lines, is stored in a 50-bit memory. This arrangement allows parallel decision processing, downscaling of abundant triggers, and priority decisions. A list of various trigger combinations is provided in Table II.

Table II Selection criteria for some special final states

EXPERIMENT	TRIGGER
1. Identified single particle inclusive and correlations	$BB \cdot ESOP \cdot 2^{-n}$; $JET \cdot ESOP$; $SP \cdot ESOP$
2. Identified pairs ($\bar{p}p$, $\bar{K}K$..)	$BB \cdot ESOP(1) \cdot ESOP(2)$
3. Jet studies and S.P. in calorimeter	$BB \cdot 2^{-n}$; $E(1) \cdot 2^{-n(1)}$ $E(2) \cdot JET(1) \cdot 2^{-n(2)}$; $E(3) \cdot JET(2)$;...
4. Flavour jets	$E \cdot E.M.(1) \cdot ESOP$; $E \cdot E.M.(2) \cdot ESOP(1) \cdot ESOP(2)$
5. Multileptons (≥ 2)	$E_{\text{e.m.}} \cdot E.M.(1) \cdot ESOP(1)$; $E.M.(2) \cdot ESOP(2)$
6. Inclusive electrons	$E \cdot E.M. \cdot ESOP \cdot 2^{-n}$
7. Correlations	$E \cdot SP(1) \cdot SP(2) \dots 2^{-n}$; $E \cdot JET(1) \cdot JET(2) \dots 2^{-n}$

Comment

The indices in parenthesis refer to a) different ESOP processors with different decision criteria or to b) one or more calorimeter sums satisfying different thresholds.

ACKNOWLEDGEMENTS

The ESOP project owes its success to many people; we are particularly indebted to its designers, T. Lingjaerde and A. Fucci, who also contributed crucially in the running-in phase. Throughout the development phase the work and advice of D. Jacobs and D. Marland were essential. S. Cairanti and G. di Tore made invaluable technical contributions. We are grateful to P. Zanella and D. Williams for constant support.

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