ON-LINE FILTERING AT THE CERN-ISR

H. Frehse
CERN, Geneva, Switzerland

ABSTRACT

During the last years it has become quite evident that one should aim at trigger systems with high selectivity in order to improve the purity of data and simultaneously remove load from the off-line processing. At the CERN ISR typical pp interaction rates are in the order of 1-3 MHz. Therefore experiments studying low cross section processes need trigger systems which provide reduction factors in the order of 10^5 to avoid dead time losses. The use of programmable devices, allowing for flexible and sophisticated decision schemes, enables experiments to gain a decisive factor in rejection after pre-triggering with more conventional devices. An overview of the different methods employed and their performance is given.

1. INTRODUCTION

There are several ISR experiments, whose goal is the study of processes with very low cross sections. To do so evidently a rather high rejectivity ($> 10^5$) is needed, which in some cases can best be gained by "on-line" filtering. The term "on-line filtering" refers to the fact, that computers or microcomputers decide on-line on the base of computations to accept or to reject events.

Before however going into a description of the different techniques employed, let me first recall some characteristic features of ISR experimentation. This should help to better understand the constraints to be met by trigger systems.

2. EXPERIMENTAL CONDITIONS AT THE ISR

The ISR is a high rate DC machine, all trigger decisions have to be made in real time. For pp-running typical luminosities are 2×10^{31} cm^{-2} sec^{-s}, which means that the total beam-beam interaction rate is in the order of 1 MHz. For the beam-gas background exact figures cannot be given, because they are experiment dependent. It can however be safely stated, that background counting rates are in most cases comparably low and relatively easy to suppress.

This situation differs from e^+e^- storage rings where the beam-beam interaction rate is small. The problem there is basically to discriminate against overwhelming backgrounds and get all events originating from beam-beam interactions.

At the ISR, experiments can collect unbiased events without any difficulty. A detector like the Split Field Magnet Detector can record a million of events in about 12 h, being only limited by the maximum speed of data acquisition, which is ∿ 25 Hz.

So in order to fully exploit the enormous luminosity which is provided by the ISR highly selective triggers have to be used. If we assume a luminosity of 2×10^{31} cm^{-2} sec^{-1} and define 10 Hz as being the maximum speed for reasonable data-taking it becomes clear that rejection factors in the order of 10^5 are needed. With lower rejectivity, one risks to be troubled by dead-time losses.

As will be shown, the use of programmable devices as part of the trigger system can help to gain a decisive factor in rejection and at the same time can remove considerable load from the off-line computers.

3. STATUS AT THE ISR

On-line filtering by programmable devices has up to now been applied for:

(a) Single particle triggers with high transverse momentum (R416, R807), with high transverse and high longitudinal momentum (R419).

(b) Total energy (R807).

A quite natural extension for the future seems to be multitrack triggers aiming at event configurations. In fact there are plans to trigger on event configurations (multiplicity) in part of the phase space (R608).

Another interesting line of development is the use of analog computers to do fast computations of the invariant mass of lepton pairs (R108).

4. WORK-SHARING BETWEEN DECISION ELECTRONICS AND FILTER COMPUTER

Before discussing the actually used filter systems, it may be appropriate to stress some principles for the work-sharing between decision electronics and filter computer.

Filter computers can only be used, when the counting rates have been reduced by the decision electronics to 5000 Hz-100 Hz to allow for typical decision times in the order of 200 μsec (microcomputer) - 5 msec (computer).

On-line filtering can further purify the data, when the space - or energy - resolution needed in order to increase the rejectivity exceeds the "granularity" accessible to the decision electronics. Accessible in this context does not necessarily mean the technical possibility or impossibility to access information, but that with the resolution needed, the amount of signals to be treated surpasses every reasonable limit. Moreover the read-out data often need corrections in order to make full use of the inherent spatial or energy resolution of the device in question.

5. THE SFM EXPERIMENT

Three of the SFM triggers include on-line filtering:

(a)	Trigger on prompt electrons	(R416).
(b)	High p_T single particle trigger at 45°	(R416).
(c)	High p_T single particle trigger at high Feynman x	(R419).

All triggers are single particle triggers covering a large solid angle and relying on prompt momentum analysis. The high p_T triggers aim at cross sections in the order of nanobarns. Similar methods are applied for all three of them, for further discussion the 45° trigger is chosen, because it is a nice example how on-line momentum analysis can be done even in an extremely inhomogeneous field configuration.

5.1 The SFM trigger

The SFM detector consits of 70 000 wires of proportional counters, an array of TOF chambers and a set of Cherenkov counters. Fig. 1 shows a top view of the SFM. The shaded area indicates the acceptance of the R416 45° high p_T trigger.

The trigger uses three levels of decision. A sketch of the hierarchy of trigger levels and the corresponding rate reduction is given in fig. 2. The rates correspond to a luminosity of 1.2×10^{31} cm^{-2} sec^{-1}, which is the maximum luminosity, where the amount of double events is still small.

The first level (FAST) uses fast OR (FOR) signals of groups of 256 wires, requiring a six-fold coincidence of "space points" in the region of acceptance to give a track candidate. The decision time is 500 nsec, the reduction factor is 25.

The second level uses the chamber memory OR's (MOR). A MOR is set if at least one of its 16 wires has been hit. The MOR's are grouped in coincidence matrices to define "roads" by seven fold coincidences. The coincidence patterns follow the wanted trajectories. The system consists in total of 112 roads, which are processed and interrogated in parallel. The decision time is 2 μsec, the reduction factor is 200.

The third level is a PDP 11/20 as on-line filter computer. The PDP reads selectively the chamber coordinates of the triggering telescope and performs track finding in the bending plane. If a track candidate has been found its transverse momentum is estimated. The event is kept whenever a track candidate has been found having a transverse momentum above threshold. The decision time is 10 msec, for a nominal cut-off at p_T = 4 GeV/c the reduction factor is 50.

5.2 The SFM on-line filter

Let us now more closely discuss the on-line filter:

(a) Hardware

The filter system$^{1)}$ consists of a PDP 11/20 equipped with a special interface allowing for selective read-out of the multiwire proportional chambers. The selectively read-out wire information$^{2)}$ is passed via a cluster box$^{3)}$, where the wire addresses are transformed into clusters. The centre of gravity of a wire cluster and its size a transferred via CAMAC into the PDP 11/20. The selective read-out is controlled by read-out masks which are loaded by the filter programme into a random access memory unit (RAM). The read-out masks are enabled by the decision electronics. By this scheme, the selective read out is steered such that only clusters lying inside a cone around the trigger road which fired are read by the filter computer.

(b) The filter algorithm

Pattern recognition is performed by searching for track candidates in the bending plane. The track finding uses a linear cumulation technique$^{4)}$. Given a set of track points $\{X_i\}$ in planes 1 to n - 1, a linear combination of all X_i is used to predict the next hit in plane n.

$$X_n = \sum_{i=1}^{n-1} a_{in} X_i \ .$$

The coordinates in plane n are tested against the prediction calculated

$$C_{1n} \leqslant X_n - \sum_{i=1}^{n-1} a_{in} X_i \leqslant C_{2n} \quad .$$

If a hit in plane n close enough to the predicted position is found, the hit in plane n + 1 is predicted from hits X_i, i = 1...n etc.

As has been shown by ref.[4)] a good approximation of the track momentum can be obtained by a linear combination of the track coordinates. It is

$$\frac{1}{p} = f(X_i) = \sum_{i=1}^{n} a_i X_i + \sum_{i,j=1}^{n} b_{ij} X_i * X_j + \ldots$$

For a limited region of configuration and phase space already the first term of the expansion gives a rather good momentum estimate. Fig. 3 shows the correlation between $1/p_T$ and its linear estimate for one of the coefficient sets used in the R416 45° trigger. One observes a very strong correlation.

In total four coefficient sets are used for trackfinding and momentum estimation. The loading of the appropriate coefficient set is controlled by a CAMAC input register indicating the detector region where a trigger occurred.

(c) Performance

The performance is best illustrated by fig. 4. After reconstruction of trigger tracks by the off-line reconstruction programme, the transverse momentum spectrum is shown for two samples recorded with and without the on-line filter. The samples are normalized to the same integrated luminosity. Given the extreme steepness of the transverse momentum spectrum one sees an impressive suppression of tracks having a transverse momentum lower than the nominal cut-off of the filter. Normalized per trigger filtered events are enriched by a factor of 50 for transverse momenta $p_T \geqslant 5$ GeV/c. Fig. 5 gives the efficiency curve as evaluated from the experimental data. The efficiency curve is in good agreement with the expectations from Monte-Carlo calculations.

5.3 168E emulator on-line

Recently it has been successfully tried at the SFM to add as an extra trigger level a 168E emulator to perform complete magnetic analysis on-line. The 168E is triggered, whenever the PDP 11/20 accepts an event and then reads selectively the MWPC data. A detailed description is given in ref.[5)]. Part of the SFM off-line reconstruction programme has been transferred to the emulator. This programme performs a quintic spline fit[6)] and in doing so makes full use of the momentum resolution, and excludes background triggers, mainly origination from superposition of low momentum tracks. The result is a background-free sample, and considerable savings in off-line computer time (200 ms per trigger on an IBM 370/168).

6. THE AFS EXPERIMENT

Experiment R807 studies hadronic jets at the Axial Field Spectrometer7). Trigger conditions involving on-line filtering are:

(a) High p_T trigger on a single charged particle.

(b) A calorimeter trigger indicating that particles collectively carry high transverse momentum.

Fig. 6 shows a sketch of the set-up used. The detector consists of an axial field magnet surrounding the intersection, containing within the volume of the field a barrel scintillation hodoscope and a cylindrical drift chamber. The magnetic field is coaxial with the ISR beams. The drift chambers consist of wedged shaped sectors, each 4° wide, and containing 42 sense wires.

6.1 The R807 high p_T trigger

The principle of the single particle high p_T trigger is as follows: the proportional chambers and the barrel counters are used to set up a sequence of increasingly more selective trigger conditions (table 1)8). Having cut down the rate sufficiently to a few kHz an ESOP processor9,10) is used to perform trackfinding and when needed estimates the momentum of tracks passing through the drift chamber. The magnetic stiffness of tracks in the bending plane is used to discriminate against low p_T tracks.

TABLE 1

Detector	Trigger	Rate	Decision time
Forward scint. hodoscope	Interaction trigger	6×10^5 s^{-1}	10 ns (1)
PC groups barrel hodoscope	Single particle pretrigger (SPT)	6×10^4 s^{-1}	60 ns (2)
Wire hits in PC1 and PC2	RAM threshold, p_T from 2 to 5 GeV	$\sim 10^4$ s^{-1}	700 ns (3)
Pulse height on radial groups or 12 d.c. wires	d.c. fast or processor	$\sim 2 \times 10^3$ 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

6.2 ESOP as on-line filter

(a) Hardware

ESOP is a microprogrammable processor for high speed data treatment. It has an instruction memory of 1 K 48 bit words, the data memory is 4 K 16 bit words and the cycle time 125 ns. Separate arithmetic units for instruction addressing, data memory addressing and calculations on the data provide the possibility to do operations in parallel. The processor has been coupled via a special interface to the electronics of the drift chambers.

(b) The filter algorithm

The drift chamber data are read-out selectively, the pretrigger points to a sector pair to be read-out. Fig. 7 shows such a sector pair. For each sector the drift time from four equally spaced groups of four wires are read out, as indicated in fig. 7. The drift times of a group of four wires are combined to "master points" i.e. the mean coordinate. The trackfinding then looks into all combinations of master points for each pair of sectors. The sagitta is computed and compared with the preset value.

(c) Performance

The performance is illustrated in fig. 8(10). One sees the transverse momentum spectrum as reconstructed by the R807 off-line chain. Keeping again in mind the extreme steepness of the p_T spectrum, the cut-off of the filter is rather clean for all cut-off values. The efficiency functions show a nice plateau.

(d) Timing

The time used slightly depends on background conditions and the nominal momentum cut-off. Typical times are 300-400 μsec per event.

6.3 The R807 calorimeter trigger

The calorimeter trigger7,8) is set up to detect very complex patterns of every deposit in the calorimeters. The information of the fast decision logic is finally condensed to "multiplicity encoded" signals, transferring in this way the multiplicity of subdivisions by electromagnetic or hadronic showers. The resulting pattern is tested against the contents of RAM's. This trigger is an example, where the complexity of trigger conditions is best met by computer techniques. The high granularity requires very complex look-up tables, which can be best supplied by using RAM's.

7. CONCLUSIONS

ISR experiments have shown that on-line filtering can be successfully employed on a high rate DC machine. In many cases it can help to get a rejectivity, which cannot be obtained with conventional methods. To do on-line filtering fast and with high efficiency:

(a) a fast and discriminant filter algorithm;

(b) a fast selective read-out system, which enables the filter to make full use of the inherent resolution of the detector;

(c) a stable set-up

are needed. On-line filtering then is a good means to purify the recorded data and remove considerable load from the off-line computers.

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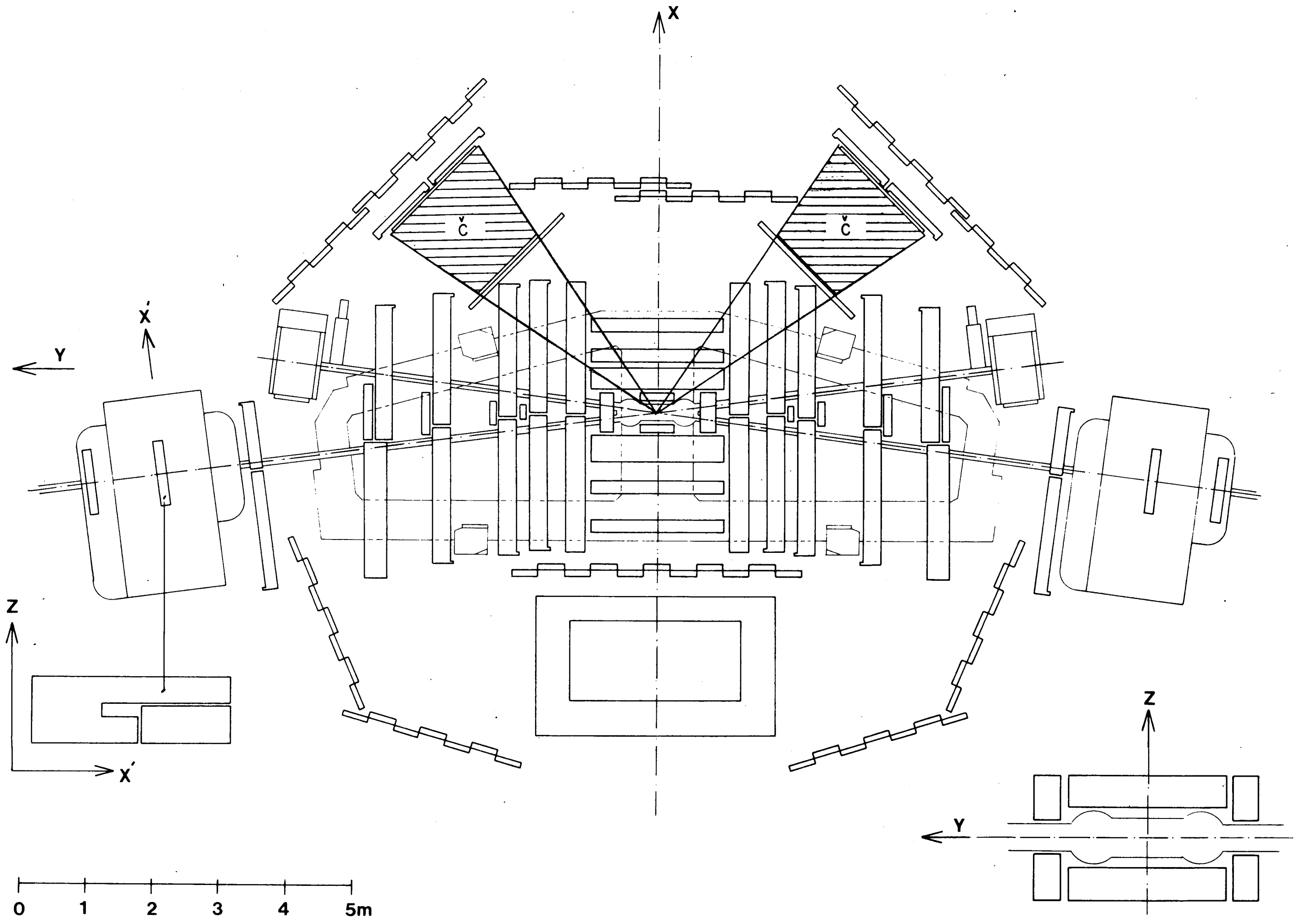


Fig. 1

Top view of the SFM detector. The acceptance of the R416 45° trigger has been indicated by boundary lines.

SFM TRIGGER AND READ-OUT SCHEME

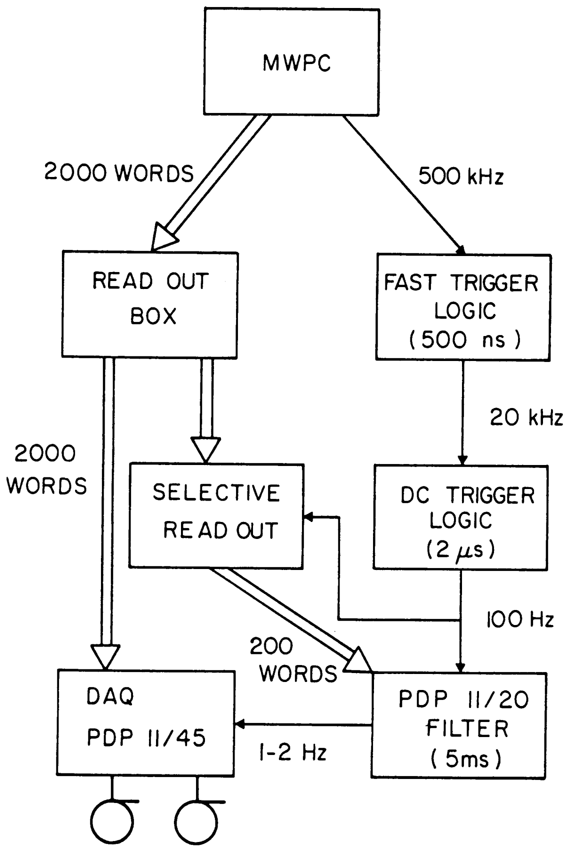


Fig. 2

Sketch of the SFM decision and read-out hierarchy. Counting rates correspond to a luminosity of 1.2×10^{31} cm^{-2} sec^{-1}

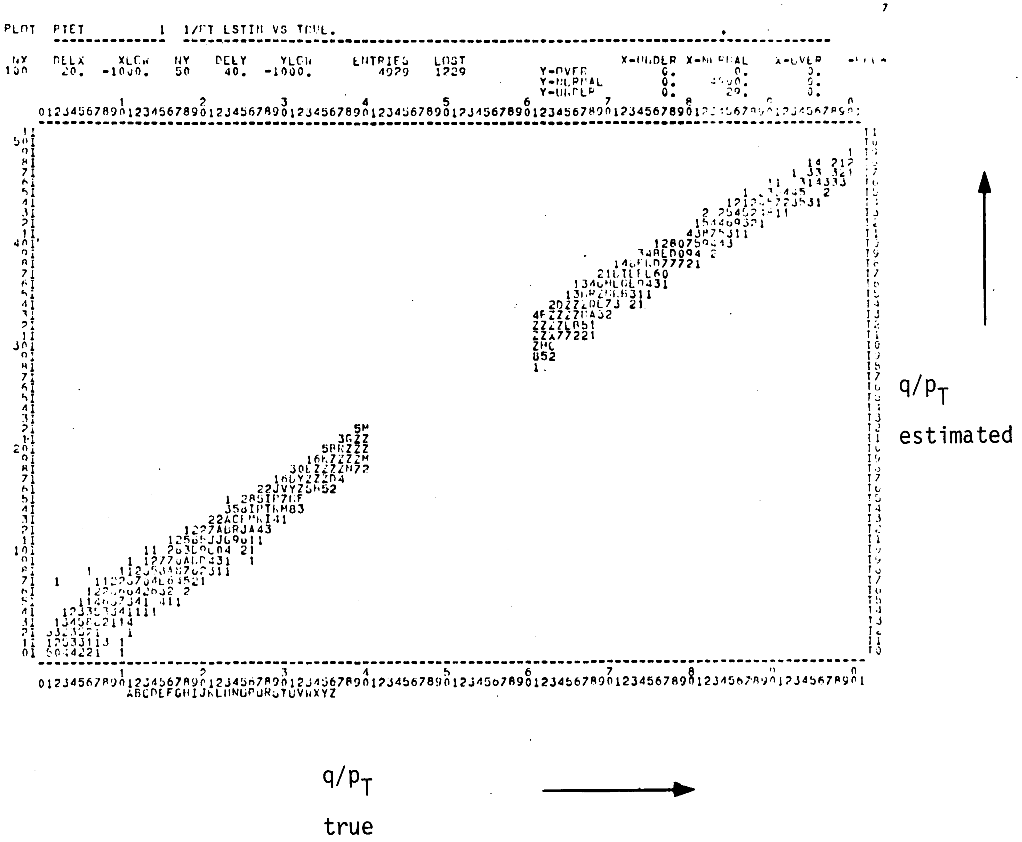


Fig. 3

Correlation between $1/p_T$ (true) and its estimate by linear coefficients

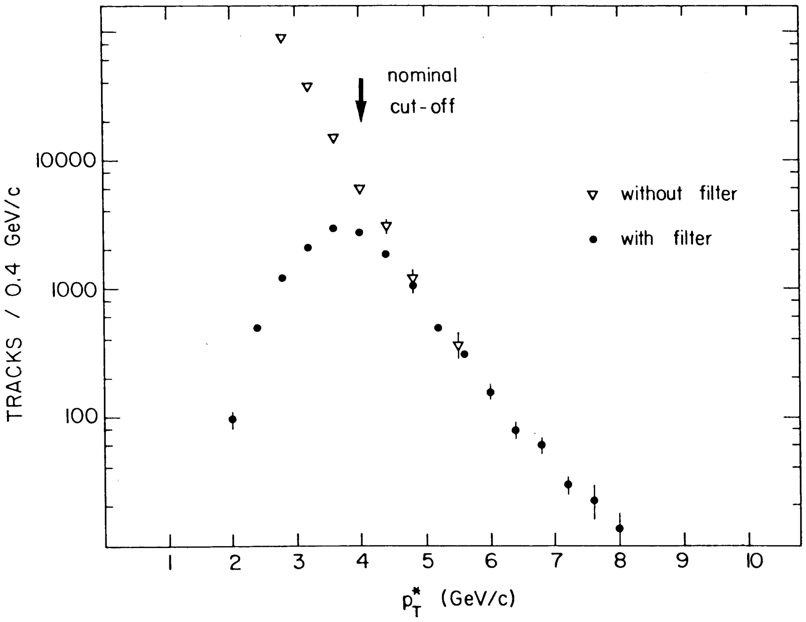


Fig. 4

Transverse momentum spectra after off-line reconstruction for on-line filtered and non-filtered data. Spectra are normalized to the same integrated luminosity. The nominal cut-off of the filter is indicated by an arrow

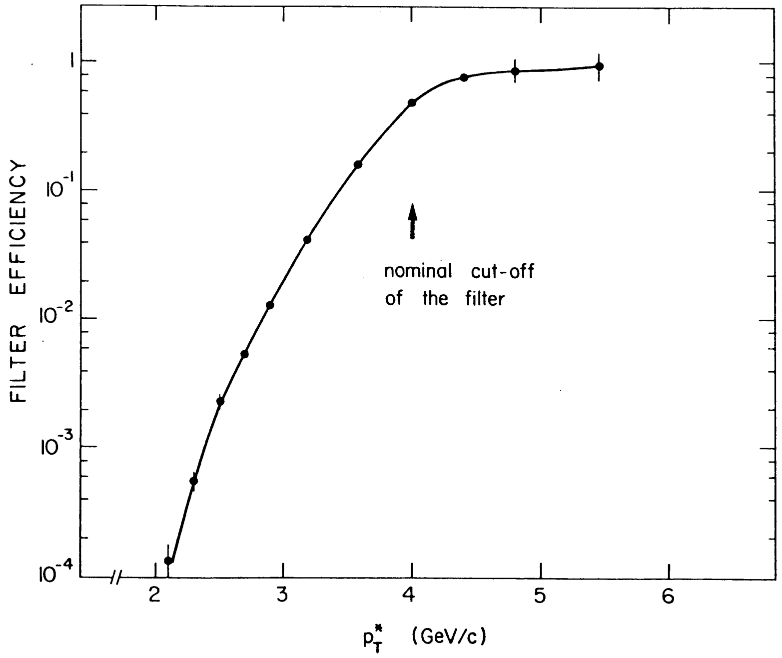
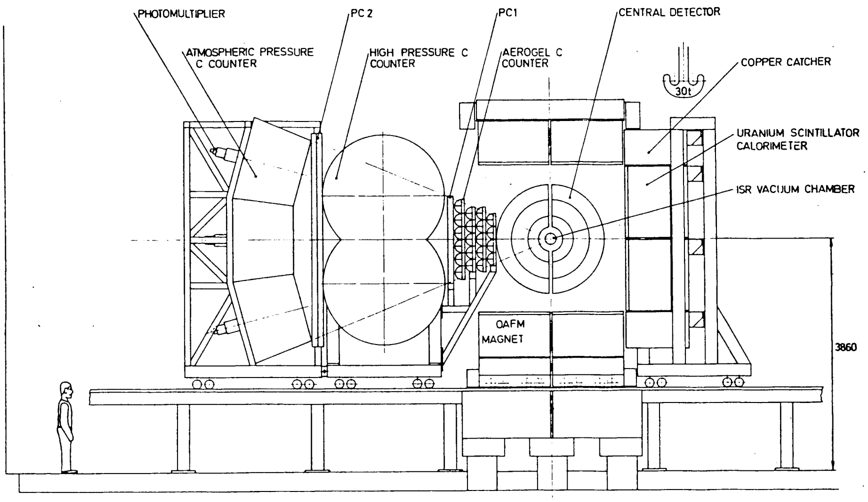


Fig. 5

Efficiency curve for the R416 on-line filter



Cross Section Showing Detector Layout R807

Fig. 6

Sketch showing the main components of the R807 detector

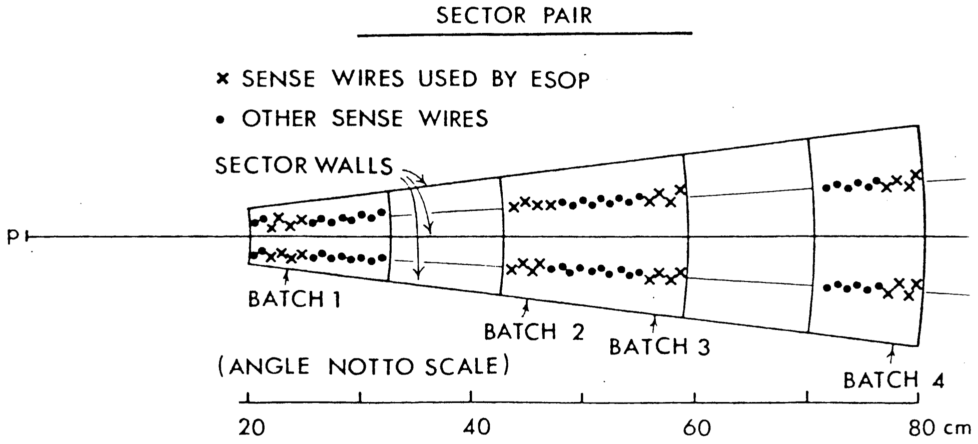
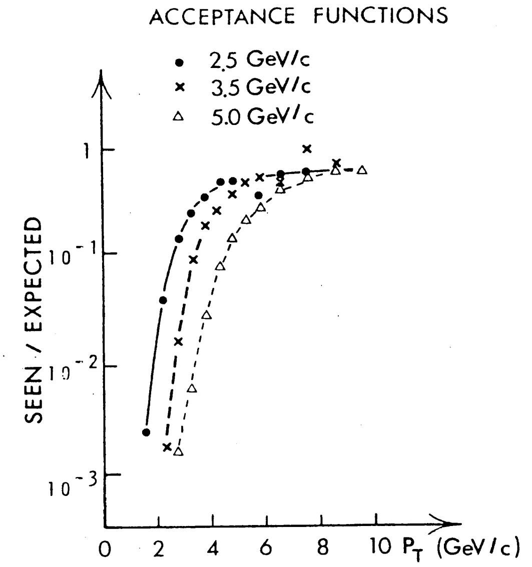
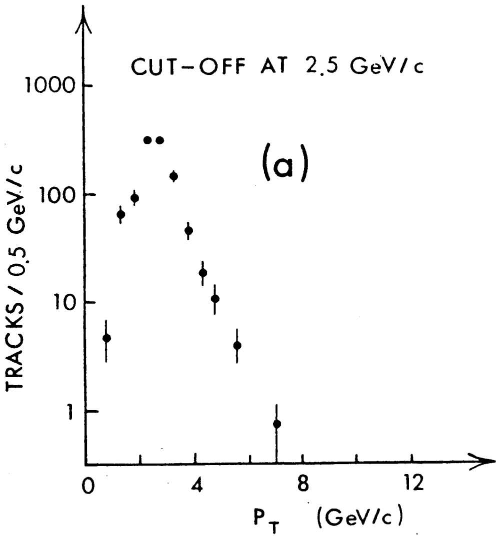


Fig. 7

A sector pair of the R807 drift chamber. The sense wires read-out by ESOP are marked by crosses





The ratio seen/expected events for various settings of the sagitta cut-off.

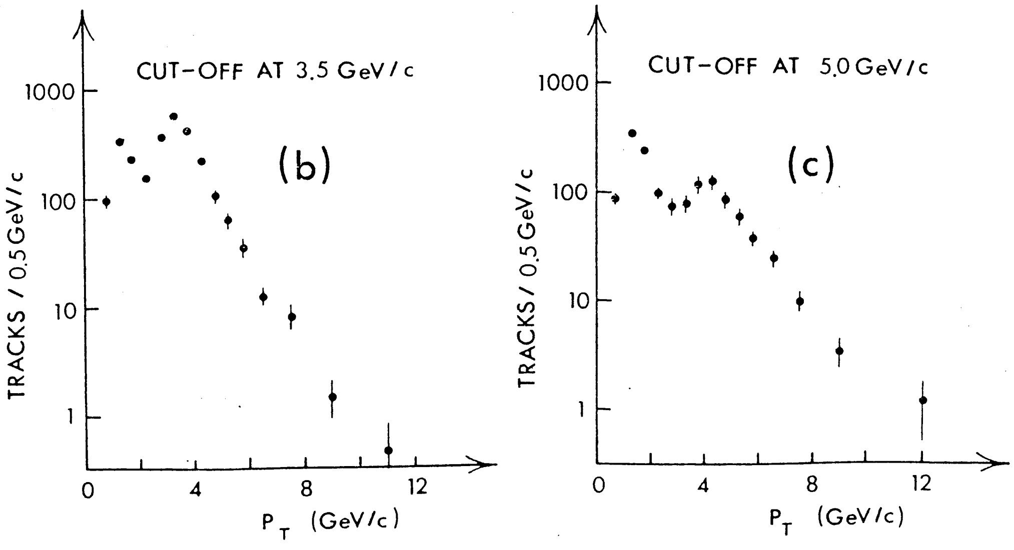


Fig. 8

Momentum spectra and acceptance functions for ESOP accepted events (R807) at various cut-off values[10)]