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QBGFMAR

AN UPDATED PHAN PACKAGE FOR COSMIC AND HALO MUON TOPOLOGICAL REJECTION IN HIGH P_T PHYSICS ANALYSIS

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Abstract

We present an updated set of topological finders for muon induced background rejection in high-P_T physics. The package is called QBGFMAR and extends the previous PHAN package QBGFIND documented in H1 note H1-10/96-498. The new features are described and the overall performance evaluated on several background and physics samples.

1 INTRODUCTION

The QBGFIND package [1] was released two years ago in order to set a coherent frame for future development of muon background topological finders within H1. QBGFMAR now extends QBGFIND on the same basis. The redundancy between finders is kept minimal. The independent detector pieces of information are associated in such a way that a detector of crucial interest for a given physics case can be easily discarded from the rejection patterns, while still making optimal use of other detectors.

The technical details for using QBGFMAR are given in appendix.

The routine **QBGFMAR(IBGFLAG)** delivers 3 levels of information:

- the result of 10 independent "safe" finders, encoded in bits 0-9 of the IBGFLAG argument. These finders are designed to ensure a minimal physics inefficiency on most physics channels.
- a set of 26 topological background discriminators. These variables quantify independent topological patterns discriminating between muon background and physics events. They can serve as input to multi-dimensional cuts or neural networks tuned to tighten the rejection power of the above safe finders. The tuning has to be adapted to each physics case.
- the result of 10 one-dimensionnal cuts and 6 two-dimensional cuts, applied on the above variables after optimization for the Charged Current case, and stored in bits 10-19 and 20-25 of IBGFLAG respectively (warning: these cuts may not be adapted to other physics channels).

These 3 levels are described in more details in the following.

2 FIRST LEVEL: THE SAFE FINDERS

The first 10 bits of IBGFLAG contain the result of the following safe finders:

- bit 0: HALAR, halo finder based on Liquid Argon information only.
- bit 1: HAMULAR, halo finder correlating the Barrel Liquid Argon deposits with the Backward Iron Endcap.
- bit 2: HAMUMU, halo finder correlating the Forward Iron Endcap with the Backward Iron Endcap.
- bit 3: HASPALAR, halo finder correlating the Liquid Argon Calorimeter with the SPACAL detector.
- bit 4: HAMUIF, halo finder correlating the Inner Forward Liquid Argon deposits with the Backward Iron Endcap.
- bit 5: COSMUMU, cosmic finder based on Muon Detectors only.
- bit 6: COSMULAR, cosmic finder correlating the Muon Detectors and the Liquid Argon Calorimeter.
- bit 7: COSTALAR, cosmic finder correlating the Tail-Catcher and the Liquid Argon Calorimeter.
- bit 8: COSTRACK : cosmic finder based on CJC information only.
- bit 9: COSLAR : cosmic finder based on Liquid Argon information only.

The finders HALAR, HAMULAR, COSMUMU, COSMULAR, COSTALAR and COSTRACK were already described in [1]. Within the QBGFMAR package COSTALAR has been extended and HAMUMU, HASPALAR, HAMUIF and COSLAR are new finders. Hereafter we provide a full description of the 10 finders for completion.

2.1 HALAR

Basic idea : Pure LAr "halo" longitudinal horizontal pattern

Algorithm :

- Divide the LAr Calo Barrel (wheels 0-5) into 36 x 26 (ϕ,z) sectors each of size 10^0 x 20 cm.
- Define for each ϕ sector :
  - $n1(\phi)$ the number of z sectors with $E(\phi, z)$ above noise threshold.
  - $n3(\phi)$ the number of z sectors with either $E(\phi - 1, z)$,$E(\phi, z)$ or $E(\phi + 1, z)$ above noise threshold.
  - $E(\phi)$ the energy of the ϕ sector integrated in z.
- Define $Emax = max(E(\phi))$, $n1max = max(n1(\phi))$.
- Flag as halo if there exists one ϕ_0 sector with :
  - [$n3(\phi_0) \geq 19$]
    OR
  - [$n3(\phi_0) \geq 14$] AND
    [no ϕ sector outside ($\phi_0 - 1$, ϕ_0, $\phi_0 + 1$) with $E(\phi) > Emax$] AND
    [at most one ϕ sector outside ($\phi_0 - 1$,ϕ_0,$\phi_0 + 1$) with $E(\phi) > \frac{Emax}{8}$] AND
    [at most one ϕ sector outside ($\phi_0 - 1$,ϕ_0,$\phi_0 + 1$) with $n1(\phi) \geq \frac{n1max}{2}$].
    OR
  - [$n1(\phi_0) \geq 12$] AND [$n1(\phi) \leq 7$ for all other ϕ sectors].

One example of background event rejected exclusively by HALAR is shown in figure 1.

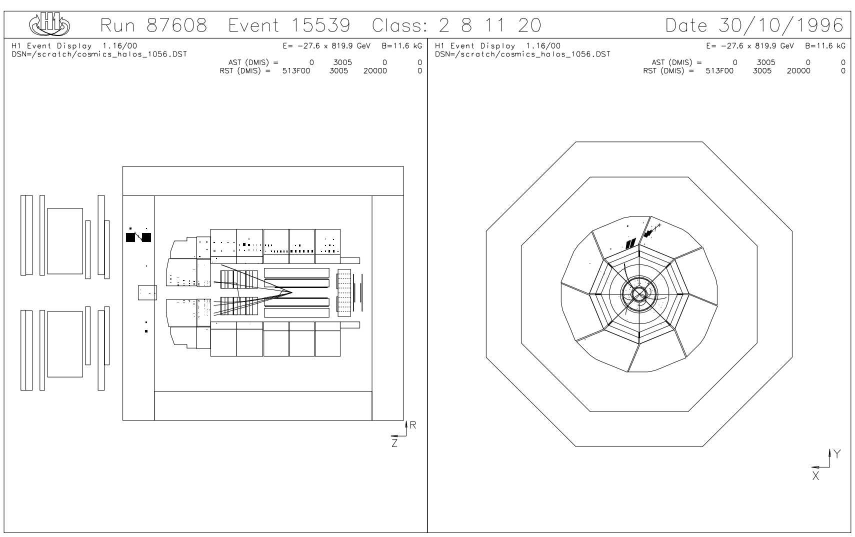

Figure 1: Example of background event rejected exclusively by HALAR.

2.2 HAMULAR

Basic idea : relaxed LAr "halo" longitudinal pattern matching a deposit inside the Backward Iron Endcap

Algorithm :

- Define :
  - LAr Calo sectors as for HALAR.
  - $D_T(\phi, \mu)$ the transverse distance between the center of gravity of a ϕ sector energy and the impact point of a backward muon track.
  - $D_T(\phi, TC)$ the transverse distance between the centers of gravity of a ϕ sector energy and a backward Tail-Catcher cluster.
- Flag as halo if there exists one ϕ_0 sector with :
  - [$E(\phi_0) > 5GeV$] AND
    [there exists one backward muon track with $D_T(\phi_0, \mu) < 30cm$].

    OR
  - [$E(\phi_0) > 5GeV$] AND
    [$n3(\phi_0) \geq 10$] AND
    [there exists one Backward Tail-Catcher cluster with $D_T(\phi_0, TC) < 30cm$].

One example of background event rejected exclusively by HAMULAR is shown in figure 2.

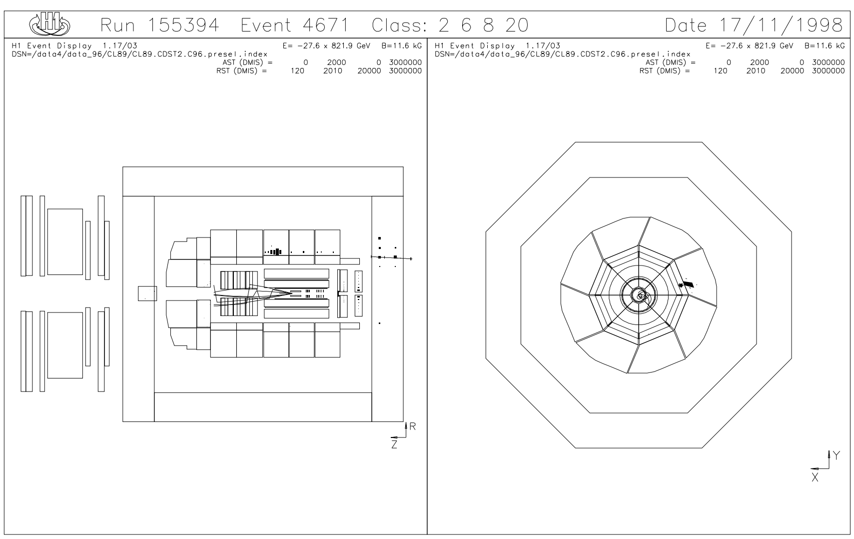

Figure 2: Example of background event rejected exclusively by HAMULAR.

2.3 HAMUMU

Basic idea : horizontal forward muon matching a deposit inside the Backward Iron Endcap

Algorithm:

- Define :
  - μ_F an horizontal forward muon track with polar angle smaller than 20^o.
  - $Nhits(\mu_F)$ the number of hits of an horizontal forward muon track.
  - μ_B an horizontal backward muon track with polar angle larger than 160^o.
  - $D_T(\mu_F, \mu_B)$ the transverse distance between the impact points of an horizontal forward muon track and a backward muon track.
  - $D_T(\mu_F, TC)$ the transverse distance between the impact point of an horizontal forward muon track and the center of gravity of a backward Tail-Catcher cluster.
- Flag as halo if
  - there exists one horizontal forward muon track with $Nhits(\mu_F) \geq 8$ and one horizontal backward muon track such that $D_T(\mu_F, \mu_B) \leq 30cm$

    OR
  - there exists one horizontal forward muon track with $Nhits(\mu_F) \geq 10$ and one backward Tail-Catcher cluster with energy larger than 0.5 GeV such that $D_T(\mu_F, TC) \leq 30cm$

One example of background event rejected exclusively by HAMUMU is shown in figure 3.

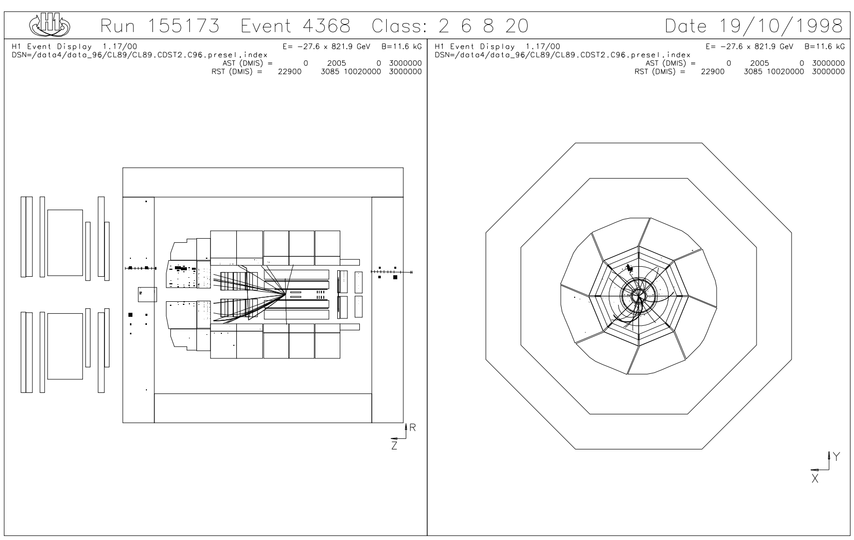

Figure 3: Example of background event rejected exclusively by HAMUMU.

2.4 HAMUIF

Basic idea : isolated inner forward Lar energy matching a deposit inside the Backward Iron Endcap

Algorithm :

- Define :
  - IF_{clust} an inner forward Lar cluster (center of gravity with $z > 291$ cm and within 117 cm from the beam axis).
  - E_{IF} the energy of the inner forward Lar cluster.
  - E_{OUT} the Lar energy located outside an horizontal cylinder of radius 25 cm centered on the inner forward Lar cluster center of gravity.
  - $D_T(IF_{clust}, \mu_B)$ the transverse distance between the center of gravity of the inner forward Lar cluster and the impact point of a backward muon track.
  - $D_T(IF_{clust}, TC)$ the transverse distance between the centers of gravity of the inner forward Lar cluster and a backward Tail-Catcher cluster.
- Flag as halo if there exists one inner forward Lar cluster with $E_{IF} \geq 10$ GeV and $E_{OUT} \leq 10$ GeV such that :
  - there exists one backward muon track with $D_T(IF_{clust}, \mu_B) \leq 30$ cm.
    OR
  - there exists one backward Tail-Catcher cluster with energy larger than 0.5 GeV and $D_T(IF_{clust}, TC) \leq 30$ cm.

One example of background event rejected exclusively by HAMUIF is shown in figure 4.

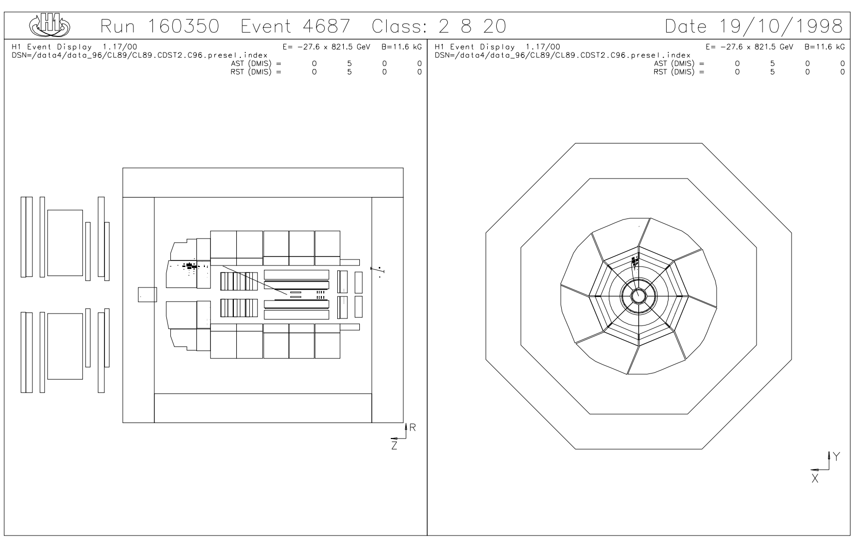

Figure 4: Example of background event rejected exclusively by HAMUIF.

2.5 HASPALAR

Basic idea : isolated inner forward Lar energy matching a deposit inside SPACAL

Algorithm :

- Define :
  - IF_{clust}, E_{IF} and E_{OUT} as for HAMUIF.
  - SP_{clust} an electromagnetic or hadronic SPACAL cluster.
  - E_{SP} the energy of a SPACAL cluster.
  - $D_T(IF_{clust}, SP_{clust})$ the transverse distance between the centers of gravity of an inner forward Lar cluster and a SPACAL cluster.
- Flag as halo if there exists one inner forward Lar cluster with $E_{IF} \geq 10$ GeV and $E_{OUT} \leq 10$ GeV, and one SPACAL cluster with $E_{SP} \geq 0.2$ GeV, such that $D_T(IF_{clust}, SP_{clust}) \leq 30$ cm.

One example of background event rejected exclusively by HASPALAR is shown in figure 5.

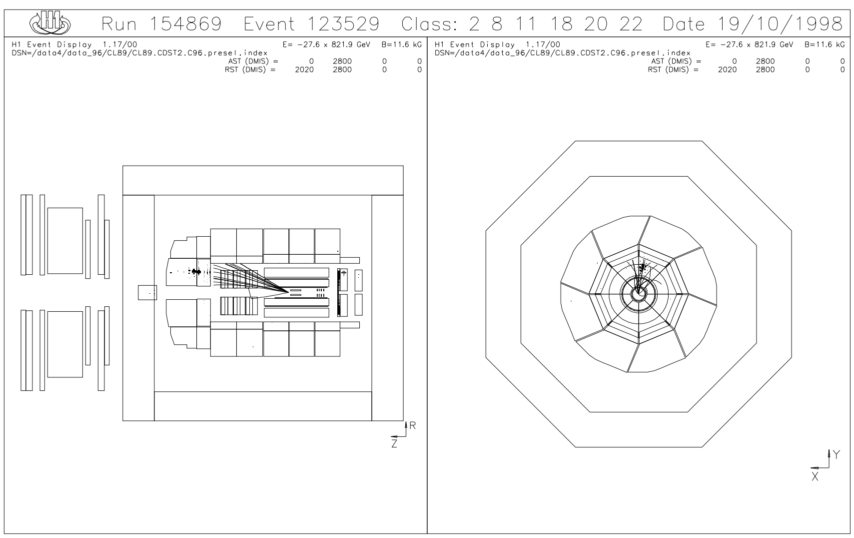

Figure 5: Example of background event rejected exclusively by HASPALAR.

2.6 COSMUMU

Basic idea : 2 opposite muon tracks of comparable direction

Algorithm :

- Flag as cosmics if there exists 2 Barrel or Backward muon tracks with :
  - Each track polar angle between 10^0 and 170^0.
  - The 2 track impact points distant by more than 4 meters.
  - Tracks directions in space matching each other within 26^0 (computed from the scalar product of the 2 unitary director vectors).

One example of background event rejected exclusively by COSMUMU is shown in figure 6.

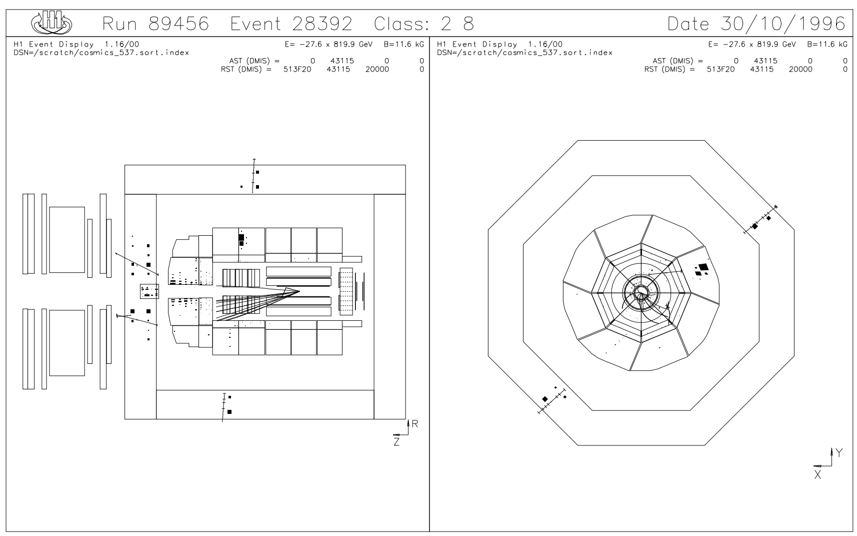

Figure 6: Example of background event rejected exclusively by COSMUMU.

2.7 COSMULAR

Basic idea : all LAr energy matching the direction of a muon track

Algorithm :

- Flag as cosmic if there exists one Barrel or Backward muon track with :
  - A polar angle between 10^0 and 170^0.
  - more than 8 hits (in order to allow a reliable direction estimation).
  - More than 90 % of the LAr energy contained inside a cylinder of radius 90 cm centered on the muon track extrapolation.

One example of background event rejected exclusively by COSMULAR is shown in figure 7 .

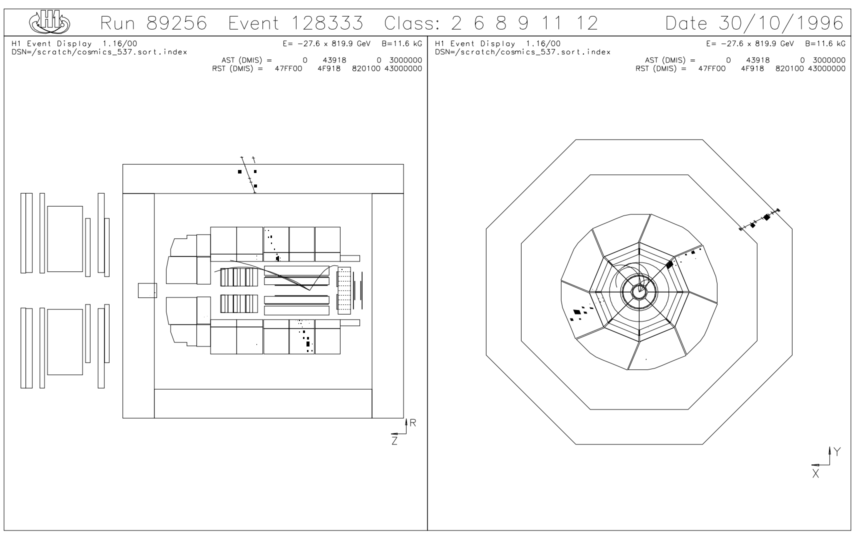

Figure 7: Example of background event rejected exclusively by COSMULAR.

2.8 Extended COSTALAR

Basic idea : all LAr energy matching the direction of 2 opposite Tail-Catcher clusters

Algorithm :

- Flag as cosmic if there exists 2 Tail-Catcher clusters with :
  - Each cluster energy greater than 0.5 GeV.
  - The center of gravity of each cluster lying at least 50 cm (resp 100 cm) away from the beam axis if located in the forward (resp backward) Iron endcap.
  - The centers of gravity of the 2 clusters distant by more than 2 meters from each other.
  - More than 85 % of the LAr energy contained inside a cylinder of radius 90 cm centered on the axis defined by the 2 centers of gravity.

One example of background event rejected exclusively by the extended COSTALAR is shown in figure 8 .

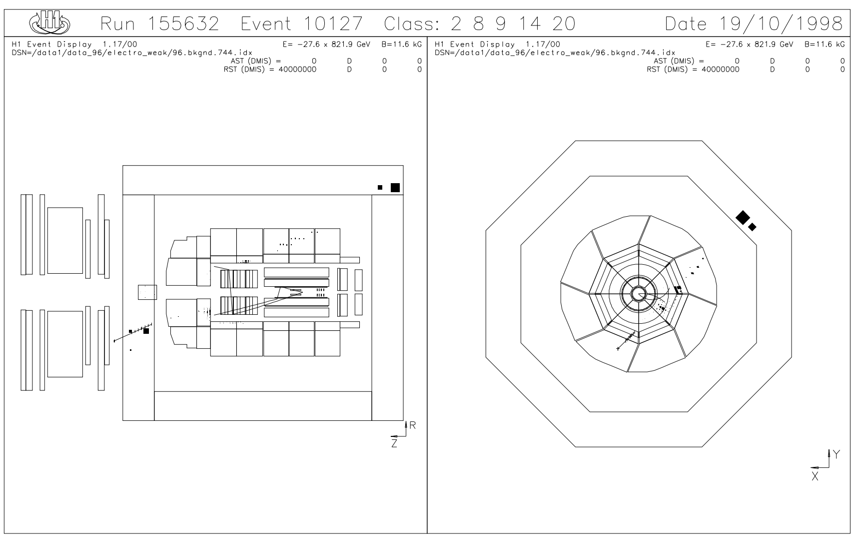

Figure 8: Example of background event rejected exclusively by the extended COSTALAR.

2.9 COSTRACK

Basic idea : 2 CJC tracks with directions exactly opposite in space

Algorithm (extra constraint on DCOS tracks) :

- Flag as cosmic if there exists no more than 20 DTNV tracks, and if there exists a DCOS track with :
  - A χ^2 smaller than 30.
  - A polar angle between 10^0 and 170^0.
  - The sum of the polar angles of the 2 associated DTNV tracks between 175^0 and 185^0.

One example of background event rejected exclusively by COSTRACK is shown in figure 9 .

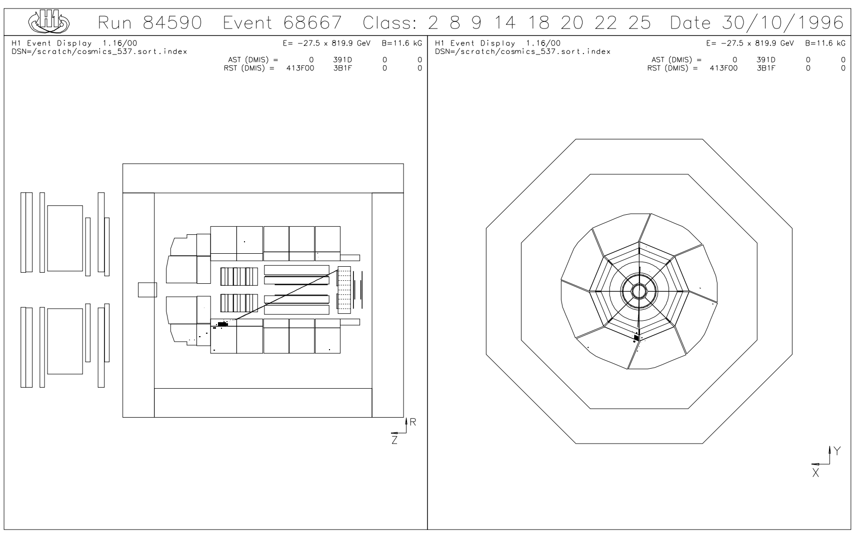

Figure 9: Example of background event rejected exclusively by COSTRACK.

2.10 COSLAR

Basic idea : "long" isolated Lar cluster with a small electromagnetic energy content

Algorithm :

- Define :
  - *Cyl* a cylinder of radius 25 cm with axis taken as the principal axis of a set of adjacent Lar clusters.
  - θ^{Cyl} the polar angle of the cylinder axis.
  - E_{IN}^{Cyl} the Lar energy located inside the cylinder.
  - E_{OUT}^{Cyl} the Lar energy located outside the cylinder.
  - ρ_{EM}^{Cyl} the electromagnetic energy fraction inside the cylinder.
- Flag as cosmic if the cylinder Cyl with the highest E_{IN}^{Cyl} has $\theta^{Cyl} \geq 20^o$ AND
  - all cylinders with $\theta^{Cyl} \geq 20^o$ have $\rho_{EM}^{Cyl} \leq 0.06$.
    OR
  - all cylinders with $\theta^{Cyl} \geq 20^o$ have $\rho_{EM}^{Cyl} \leq 0.5$ and $E_{OUT}^{Cyl} \leq 6$ GeV.

One example of background event rejected exclusively by COSLAR is shown in figure 10.

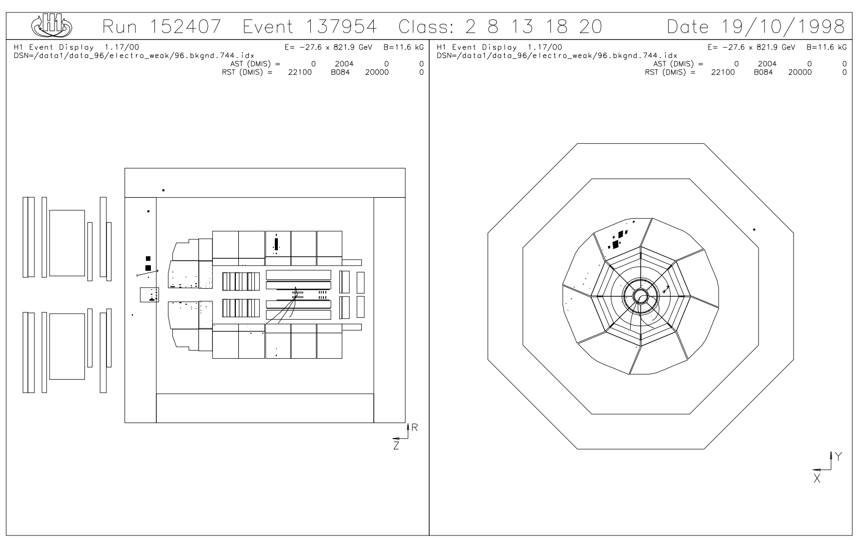

Figure 10: Example of background event rejected exclusively by COSLAR.

3 SECOND LEVEL: THE BACKGROUND DISCRIMINATORS

A set of 26 topological variables has been designed in order to quantify the topological patterns which are expected to discriminate between physics and background events. These variables are in most cases inspired by the previous safe finders but allow a tightening or further optimization of their action through proper tuning adapted to each physics case. The background discriminators can be input to either simple one-dimensional cuts, multi-dimensional cuts or neural networks. In all cases the exact cuts will have to be adjusted as function of the required background rejection power and the tolerated physics inefficiency. In order to make such an optimization easier, we have stored on ACS two files of "minimum-biased" halo and cosmic events recorded during luminosity runs and selected in the CC analysis context requiring a vertex and a calorimetric missing P_T larger than 25 GeV. The event file names are:

/acs/data/97/highq2/nonep/HALOS96.PT25.EV2319.DST

/acs/data/97/highq2/nonep/COSMICS96.PT25.EV1575.DST

These samples may not be perfectly adapted to each particular physics case but will help guessing a first set of reasonable cuts.

The list and definition of the background discriminators are given hereafter. In case a variable is undetermined (for example if no muon track exists for a muon related variable) a default value is set and chosen such that it corresponds to the "physics" region of the variable range.

3.1 Halo discriminators

- **DVN1PHI :** $\max(n1(\phi))$, where $n1(\phi)$ is defined as for HALAR.
- **DVN11PHI :** $\max(n1(\phi))$, excluding the ϕ sector maximizing $n1(\phi)$.
- **DVN3PHI :** $\max(n3(\phi))$, where $n3(\phi)$ is defined as for HALAR.
- **DVE3PHI :** $E(\phi_3)$, energy of the ϕ sector maximizing $n3(\phi)$.
- **DVE33PHI :** $\max(E(\phi))$, excluding the ϕ sector maximizing $n3(\phi)$.
- **DVDMUBW :** minimal transverse distance between the center of gravity of the highest-P_T Lar cluster and the impact point of a backward muon track (default = 600 cm).
- **DVDMUMU :** transverse distance between the impact points of the forward and backward muon tracks of minimal and maximal polar angle respectively, selected as for DVTHMUFW and DVTHMUBW (default = 600 cm).
- **DVDMUTC :** minimal transverse distance between the impact point of a forward muon track and the center of gravity of a backward TC cluster, both selected as in HAMUMU (default = 600 cm).
- **DVTHMUFW :** minimal polar angle of forward muon tracks with more than 8 hits (default = 90^o).
- **DVTHMUBW :** maximal polar angle of backward muon tracks (default = 90^o).
- **DVEFOUTH :** total Lar energy fraction located outside the horizontal cylinder of radius 25 cm centered on the center of gravity of the highest-P_T Lar cluster (default = 1).
- **DVDISPRH :** radial dispersion (RMS) with respect to cylinder axis of the Lar energy located inside the horizontal cylinder defined for DVEFOUTH (default = 25 cm).
- **DVDIFSP :** minimal transverse distance between the centers of gravity of the highest-P_T Lar cluster and a SPACAL cluster as defined in HASPALAR (default = 600 cm).

3.2 Cosmic discriminators

- **DVSPMUMU :** maximal scalar product of the director vectors of 2 opposite muon tracks selected as in COSMUMU (default = 1).
- **DVEFMU :** total Lar energy fraction located inside a cylinder of radius 90 cm centered on the extrapolation of a muon track selected as in COSMULAR (default = 0).
- **DVEFTC :** total Lar energy fraction located inside a cylinder of radius 90 cm centered on the direction defined by 2 opposite TC clusters selected as in the extended COSTALAR (default = 0).
- **DVEFEMC :** Lar electromagnetic energy fraction located inside the highest energy cylinder selected as in COSLAR (default = 1).
- **DVEFOUTC :** total Lar energy fraction located outside the cylinder selected for DVEFEMC (default = 1).
- **DVDISPRC :** radial dispersion (RMS) with respect to cylinder axis of the Lar energy located inside the cylinder selected for DVEFEMC (default = 25 cm).

3.3 Miscellaneous discriminators

- **DVDTCLU :** minimal distance in the $\eta - \phi$ plane between the center of gravity of the highest-P_T Lar cluster and a good drift-chamber track (default = 10 rad).
- **DVTHCLUM :** polar angle with respect to the vertex of the center of gravity of the highest-P_T Lar cluster.
- **DVPTCLUM :** P_T of the highest-P_T Lar cluster.
- **DVETTRA :** scalar transverse energy carried by good drift-chamber tracks.
- **DVETCAL :** Lar scalar transverse energy.
- **DVTDCAMU :** minimal DCA to the beam axis of barrel muon tracks with more than 14 hits (default = 0 cm).
- **DVTHDTNV :** minimal polar angle difference (modulo 180^o) between 2 DCOS tracks selected as in COSTRACK (default = 180^o).

4 THIRD LEVEL: THE CC-OPTIMIZED CUTS

Bits 10 to 25 of **IBGFLAG** store the results of cuts applied on the background discriminators after optimization for the inclusive Charged-Current analysis at $P_T \geq 12$ GeV.

4.1 One-dimensional cuts

IBGFLAG :

- bit 10 : DVN3PHI $\geq$ 15.
- bit 11 : DVDMUBW $\leq$ 50 cm.
- bit 12 : DVDMUMU $\leq$ 200 cm.
- bit 13 : DVDIFSP $\leq$ 30 cm.
- bit 14 : DVSPMUMU $\geq$ 0.8.
- bit 15 : DVEFOUTH $\leq$ 0.05.
- bit 16 : DVEFOUTC $\leq$ 0.02.
- bit 17 : DVEFMU $\geq$ 0.8.
- bit 18 : DVDISPRH $\leq$ 2 cm.
- bit 19 : DVTDCAMU $\geq$ 40 cm.

4.2 Two-dimensional cuts

IBGFLAG :

- bit 20 : DVDTCLU $\geq$ 0.2 rad and DVEFEMC $\leq$ 0.1.
- bit 21 : DVDTCLU $\geq$ 0.5 rad and DVEFMU $\geq$ 0.05.
- bit 22 : DVDISPRC $\leq$ 5 cm and DVEFTC $\geq$ 0.25.
- bit 23 : DVDISPRC $\leq$ 5 cm and DVEFMU $\geq$ 0.05.
- bit 24 : DVDISPRC $\leq$ 4 cm and DVEFOUTC $\leq$ 0.05.
- bit 25 : DVTHCLUM $\geq 20^o$ and DVETTRA/DVETCAL $\leq$ 0.015.

5 PERFORMANCE

The physics inefficiency induced by the safe finders on high-P_T channels has been estimated using:

- 10000 data (96) NC's with $P_T^e > 15$ GeV and 48000 Monte-Carlo NC's with $Q^2 > 100$ GeV^2.
- 600 data (94) Pseudo CC's with missing $P_T > 25$ GeV, 500 data (94-97) CC's with missing $P_T > 25$ GeV and 38000 Monte-Carlo CC's with missing $P_T > 12$ GeV.
- 15000 data (96) gamma-p events with 2 jets of $P_T > 15$ GeV each and 28000 Monte-Carlo gamma-p events with 1 jet of $P_T > 6.5$ GeV.
- 10000 Monte-Carlo QED Compton events.

The resulting numbers are summarized in table 1. The physics inefficiencies are typically of the order of one permil and never exceed one percent.

	Physics inefficiency (% of physics events rejected)						
Topological	NC		CC		γp		Compton
finder	Data	MC	Data	MC	Data	MC	
HALAR	0.05	0.07	0.7	0.1	0.1	0.2	0.02
HAMULAR	0.01	0.02	0	0.01	0.1	0.1	0
HAMUMU	0	0.02	0	0	0.01	0.02	0
HAMUIF	0	0	0	0	0	0	0
HASPALAR	0	0.01	0	0.01	0	0	0.02
COSMUMU	0.01	0.01	0	0	0.1	0.1	0
COSMULAR	0	0	0	0.02	0	0	0
COSTALAR	0.07	0.08	0.6	0.1	0	0.4	0
COSTRACK	0.04	0.06	0	0	0.1	0	0.1
COSLAR	0	0.08	0	0.5	0.01	0.05	0.3

Table 1: Physics inefficiency (in percents) of the safe background finders described in section 2. See main text for a full description of the event samples.

Background rejection can be significantly improved when complementing the safe finders with the background discriminators described in section 3. As an example figure 11 illustrates the potential of a correlation between DVDTCLU and DVEFMU in the context of the low P_T ($P_T > 12\ GeV$) Charged Current analysis. For this channel application of the CC-optimized cuts of section 4 in combination with the safe finders leaves a residual background contamination of a few % for a physics inefficiency of 3 %.

6 SUMMARY

The QBGFMAR package extends the QBGFIND set of muon background topological finders with additional halo and cosmic finders based on new detector pieces of information and correlations. This allows an improved background rejection in high-P_T channels while keeping the physics inefficiency at a low level. In addition QBGFMAR introduces a set of background discriminators providing an increased flexibility in optimizing the background rejection as function of the physics case. The method has already proved its potential in the context of the Charged Current analysis. In the future QBGFMAR could still be extended making profit of new detectors recently made operational like the CST.

Acknowledgements

We are grateful to B. Heinemann, J. Phillips, J. Rauschenberger, K. Rüter and Z. Zhang for their suggestions and contributions in debugging the package.

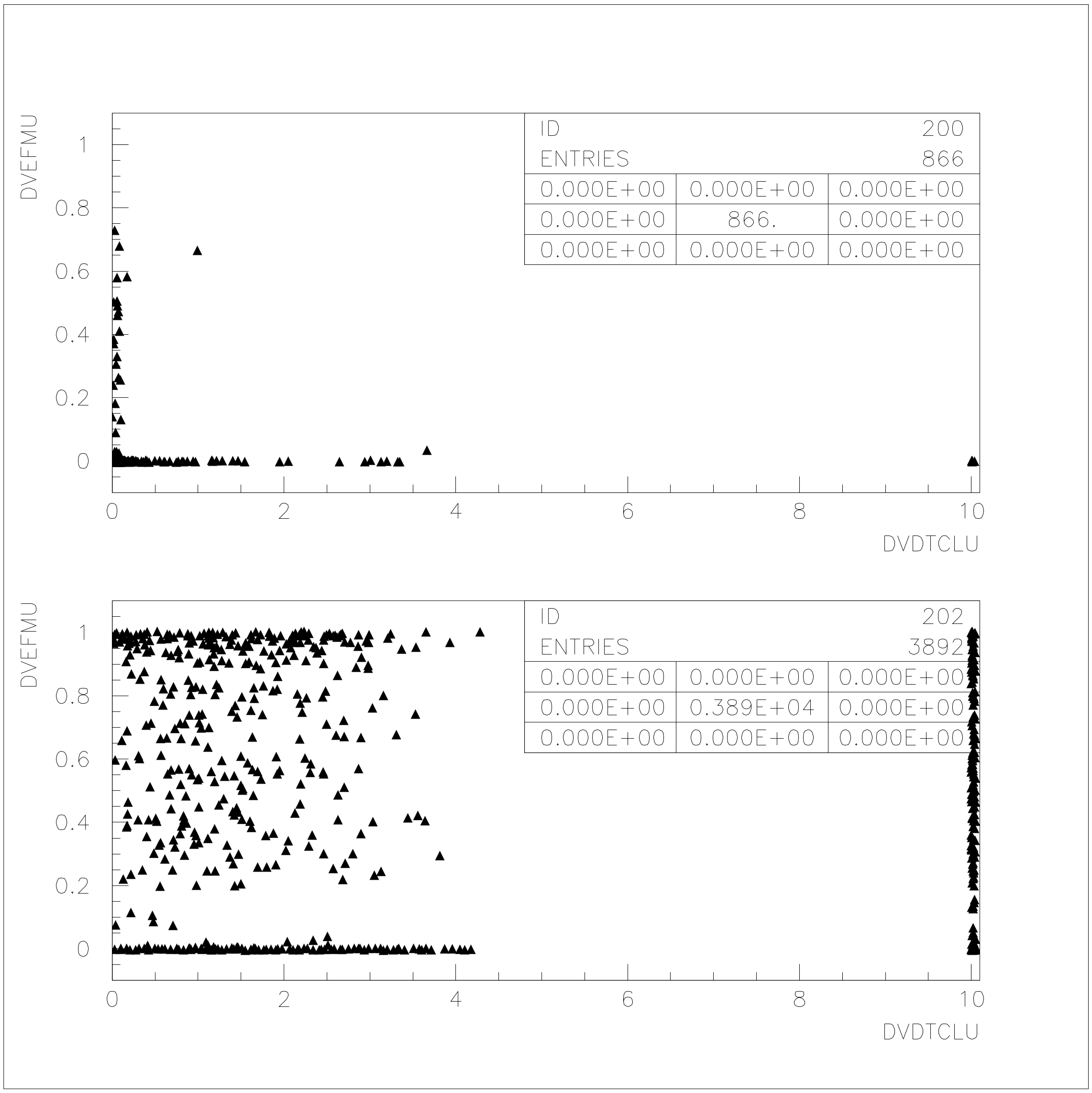

Figure 11: Correlation between the background discriminators DVDTCLU and DVEFMU. Upper plot: CC data physics sample with $P_T \geq 12$ GeV; lower plot: muon background sample.

References

[1] I. Négri et al., "A minimal comprehensive set of muon background topological finders for high P_T physics analysis", H1 note H1-10/96-498.

APPENDIX : QBGFMAR technical description (version 1.00/00)

Location : H1PHAN version $\geq$ 3.00/03.
Main routine : QBGFMAR(IBGFLAG)
Input parameters : none
Steering bank : QBGM

```
*=========================================================================
*                            QBGM
*
*   Steering bank for cosmics/halos finder QBGFMAR
QBGM 0 /
*=========================================================================
*                   global steering
*
 'IHL1'  1  ! D = 1    ! (1/0) enabled/disabled the halo finder HALAR
*
 'IHL2'  1  ! D = 1    ! (1/0) enabled/disabled the halo finder HAMULAR
*
 'IHL3'  1  ! D = 1    ! (1/0) enabled/disabled the halo finder HAMUMU
*
 'IHL4'  1  ! D = 1    ! (1/0) enabled/disabled the halo finder HASPALAR
*
 'IHL5'  1  ! D = 1    ! (1/0) enabled/disabled the halo finder HAMUIF
*
 'ICO1'  1  ! D = 1    ! (1/0) enabled/disabled the cosmic finder COSMUMU
*
 'ICO2'  1  ! D = 1    ! (1/0) enabled/disabled the cosmic finder COSMULAR
*
 'ICO3'  1  ! D = 1    ! (1/0) enabled/disabled the cosmic finder COSTALAR
*
 'ICO4'  1  ! D = 1    ! (1/0) enabled/disabled the cosmic finder COSTRACK
*
 'ICO5'  1  ! D = 1    ! (1/0) enabled/disabled the cosmic finder COSLAR
*
 'IVAR'  1  ! D = 1    ! (1/0) enabled/disabled BG discriminators computation
*=========================================================================
```

Output parameter: IBGFLAG, 32-bit INTEGER described in sections 2 and 4.

Output variables: set of 26 background discriminators stored in the common **QBGVARB** included in the PHAN macro **QQBGM**, and described in section 3.