ANAL/ELECTROWEAK/CDFR 1260
August 6, 1990

Cosmic Filtering of Central Muon Events

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Abstract

This note describes a cosmic ray muon filter using CTC tracking information. The effectiveness of the filter as applied to the $W \rightarrow \mu\nu$ and $Z^{\circ} \rightarrow \mu^{+}\mu^{-}$ data samples was tested using scans, electron data, alternate back-to-back cosmic ray finders, and hadron TDC information. For these samples of stiff, isolated muons we found that the filter accepts 99.8% of the $p\bar{p} \rightarrow \mu X$ events while leaving less than 0.4% of cosmic ray background. The filter can be found in C$MUO:CMUCOS.CDF. Beware that the filter requires that the CTCD bank exist.

1. Filter

(1) Structure of Cosmic events

Figures 1 and 2 show a typical event with cosmic ray muons in the CTC and Side-view displays. In most cases, events with cosmic rays overlapping real minimum bias interactions were collected as muon trigger data. Tracks from cosmic rays have several characteristics that help distinguish them from tracks coming from $p\bar{p}$ collisions.

- Back-to-back tracks. Clearly, this is the most striking feature. However, if the track crosses the CTC far from the orgin and at a large angle, the second leg may not be reconstructed. In this case, cosmics are rejected by simply requiring $|z_0| < 60$ cm, as is standard in most analyses. But the filter must not reject Z°'s decaying into back-to-back tracks.
- Non-overlap with the primary event vertex. Requiring the z_0 of the track within 2 cm in z of the vertex and a fiducial cut of $|z_{\text{event vertex}}| < 60$ cm, cosmic ray tracks appear to come from the $p\bar{p}$ collision vertex less than 0.1% of the time. The impact parameter in the $r\phi$-plane is also generally larger than for tracks from the collision.

- VTPC vertex class. If the vertex is associated with cosmic muon tracks, the VTPC track segments used in the vertex reconstruction will have few hits used ($\sim$ 50 as compared with a nominal average of $\sim$ 300 in minimum bias beam-beam interactions), resulting in an vertex classfication of less than 8 [2]. However, $W^{\pm}$ and Z° events often have quiet underlying events, and we find that 1.4% of the events in our high p_t isolated muon sample have vertex class < 8, so this cut is not used in the filter.

- Timing. Track reconstruction is very sensitive to the drift time measurement of the CTC hits. The longitudinal spread of the proton and anti-proton bunches creates a 3 ns window around the nominal $p\bar{p}$ crossing time, but the CTC track finding recognizes tracks during about 30 ns. The time of the track relative to beam-crossing is measured.

- Particle direction. The tracking code makes time-of-flight corrections assuming that the particle travels from the center of the CTC outwards. This is always wrong for one cosmic ray leg. The result is that one leg usually is poorly measured, having fewer hits, larger residuals, a poor χ^2, and/or failure of the stereo reconstruction (2-dimensional track).

- Time-of-flight. Particles from a $p\bar{p}$ collision reach the outer layers of the detector at about the same time. A cosmic ray takes about 20 ns to travel from the top hadron TDC's to the bottom, and about 9 ns to traverse the CTC.

(2) Filtering Algorithm

Based on the above information, the cosmic filter C$MUO:CMUCOS.CDF was written to reject muons which fall into one of following categories (no beam-constraints are applied):

- Muon not attached to any vertex with $|z_{vtx}| < 60$ cm (any vertex class > 0).
- Muon candidate track is not from a "primary" event vertex, that is, $|D_0| > 0.5$ cm or $\Delta z = |z_{vtx} - z_{track}| > 5$ cm.
- There is a "bad" track with $p_t > 10$ GeV within 2° of back-to-back in ϕ, where "bad" means

  Not 3-D, or

  $|D_0| > 0.5$ cm or $\Delta z > 5$ cm, or

  Low fraction of possible hits (see CTCUFR in C$MBS:CTRSEL.CDF), or

  Too few track segments (see CTCSEG in C$MBS:CTRSEL.CDF, and [1]).

- There is a good back-to-back track in ϕ, but $|\eta_{\mu} + \eta_{track}| < 0.2$ and VEL> 0.5.

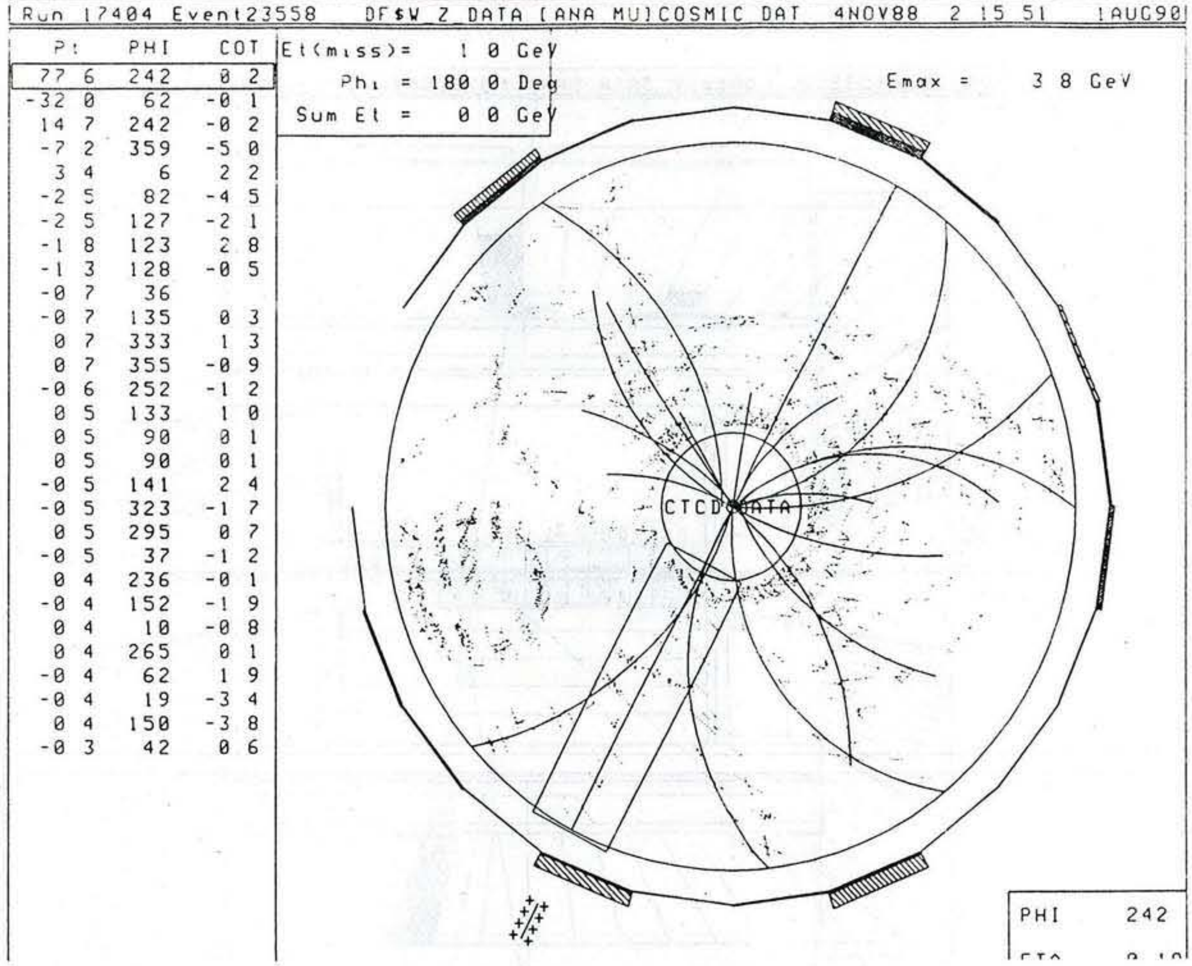

Figure 1: Typical cosmic ray event in the CTC.

VEL is a variable returned by the routine CTCOSM, called by C$MUO:CMUCOS.CDF. (Code is in the same file with CMUCOS). The routine re-fits the two back-to-back legs as a single track, and finds the particle velocity, normalized to the speed of light, that gives the best fit. Hence, a cosmic ray has VEL$\approx$ 1 and a Z° gives VEL$\approx$ 0. Also calculated is the time that the track passes through the center of the CTC, which is within ± 3 ns for $p\bar{p}$ events.

Figures 3 and 4 give a feel for the Δz and D_0 cuts, respectively. In each plot, the solid histogram is for events flagged as cosmic rays. (The D_0 distribution has been corrected for the beam offset relative to the orgin of the CDF coordinate system).[5] Superimposed on the plots (dashed histogram) is the same distribution for the W and Z events. It's clear that the distributions for cosmic rays are much broader, and in the case of Δz the looseness of the 5 cm cut is apparent. For both plots, solid histogram has been normalized to match the peak in the dashed curve.

2. Efficiency of Filter

Results are based on 4521 events with high p_t central muon candidates, collected

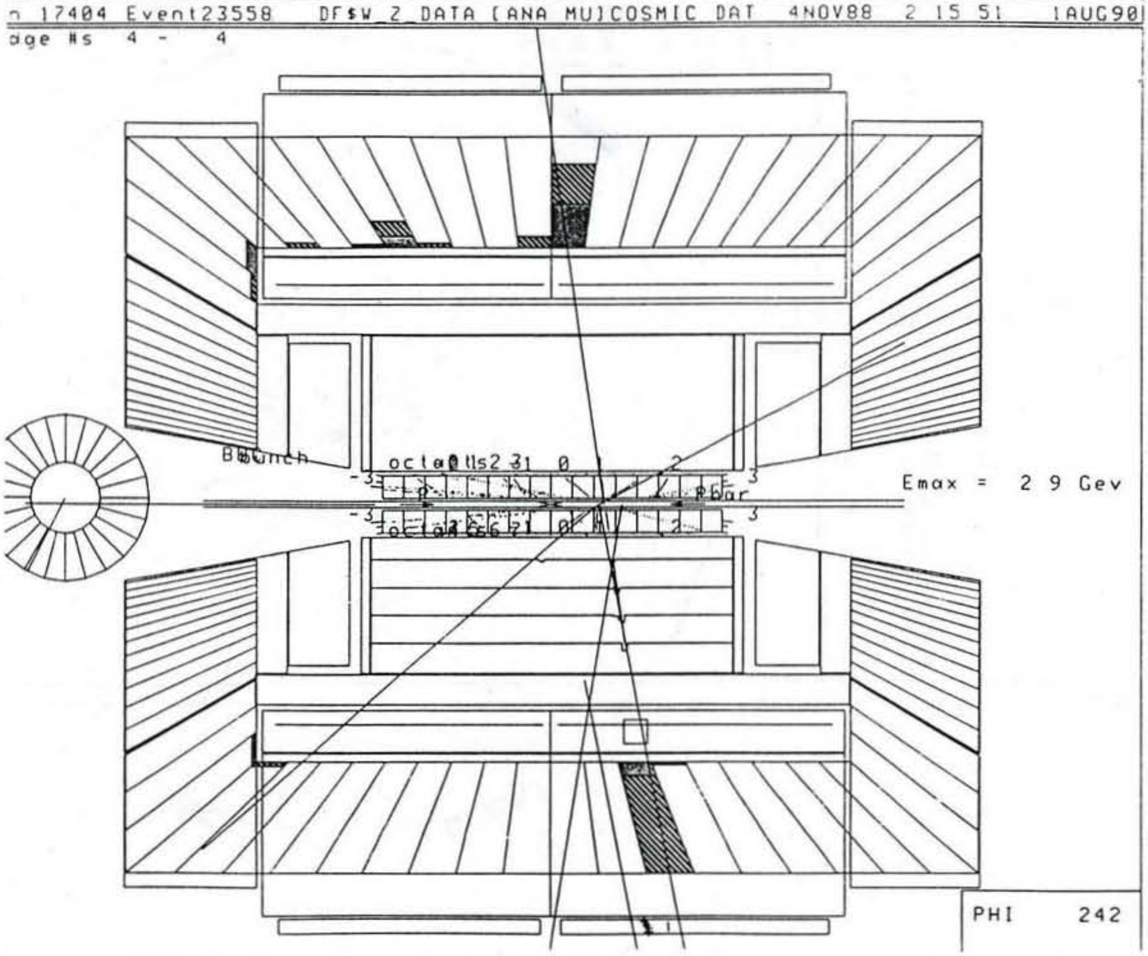

Figure 2: Same event as in figure 1, seen from the side.

during the 1988-1989 running period, corresponding to an integrated luminosity of about 3.7 pb^{-1}. This data sample is described in CDF-1263. The cuts used to identify high p_{T} muon objects in the central region are listed in table 1. Note that the isolation cut is slightly different than that used in the standard W and Z sample (CDF-1263), but the difference is immaterial. 129 μ candidates were identified as coming from cosmic rays, leaving 4392 events.

We scanned all the events rejected by the flagger and found that 4 muon candidates from real interactions were falsely identified as cosmic rays. We scanned 1000 events from the sample of isolated high p_t muons, as well as all events with primary vertex class < 8 as identified by the VTPC code [2], and found 2 cosmic ray events that were missed by the flagger. Furthermore, 3 events were identified as cosmic rays but are borderline cases. That is, we are unable to determine conclusively whether the events are from cosmic rays or from the $p\bar{p}$ collision. Hence we conclude that the flagger is better than

$$\frac{3000-7}{3000} = 99.8\%$$

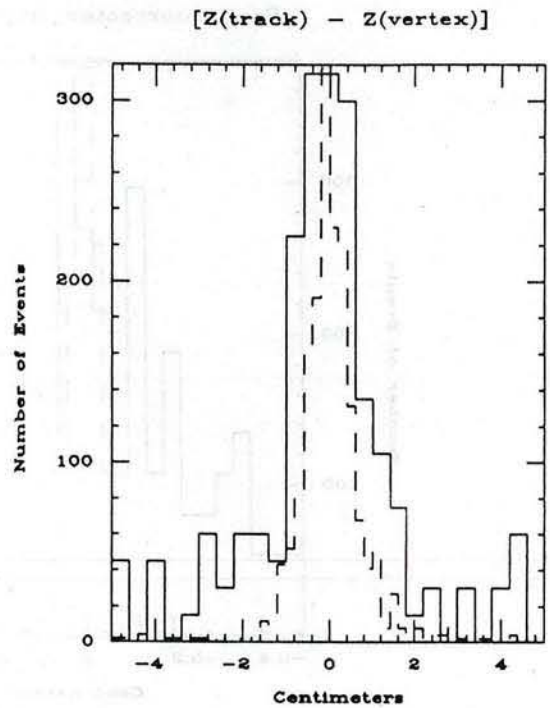

Figure 3: Difference between event vertex and z_0 of muon track. The solid histogram is for those events flagged as cosmic rays. The dashed histogram is for the events not flagged as cosmics.

efficient for W/Z events, and that the filtered sample contains less than

$$\frac{3}{1000} + \frac{2}{3000} = 0.37\%$$

cosmic background.

3. Cross-checks

Our confidence in the final scan tallies comes from a series of cross-checks that we performed on the filter. Cross-checking helped us to find biases in our algorithm as well as coding bugs, and we modified the filter accordingly. The methods used were

- C$MUO:CMCOSM.CDF (back-to-back tracks, and Hadron TDC information);
- Electron W and Z samples;

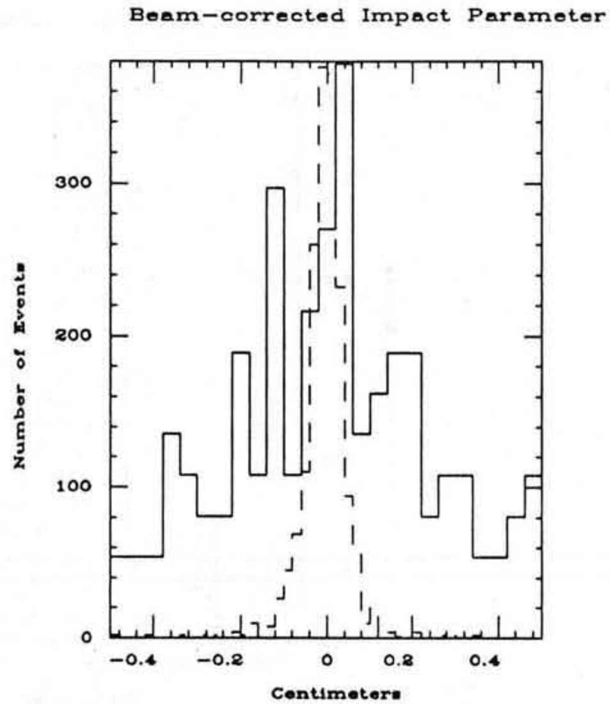

Figure 4: Impact parameter in the $r\phi$-plane, corrected for the beam offset. The solid histogram is for cosmic rays. The dashed histogram is for $p\bar{p}$ events.

- Weighted errors back-to-back track search.

(1) CMCOSM

C$MUO:CMCOSM.CDF is an older cosmic ray flagger that uses a slightly different back-to-back track searching algorithm. The biggest difference is that there is a minimum track quality requirement for the back-to-back track, and good 3-D tracks back-to-back are cosmic candidates. Since CMUCOS looks for any 'bad ' track candidate back-to-back with the muon, if a pattern recognition error forms a track from random hits in the CTC at 180° from the muon, that "track" could be misidentified as the second leg of a cosmic ray. Of the 4 to 7 events misidentified as cosmic rays, all look like soft dijet events. The muon candidate would be a pion that punched through, decayed, or found a crack while the 2^{nd} leg would be a track (most likely a misreconstruction, but possibly real) in the second jet. The minimum track quality cut saves these events, but also accepts small number of cosmic rays. CMCOSM also flags events with a good, 3-D track back-to-back with the muon as cosmics, and rejecting some Z° events.

Passes CTRSEL track quality		
p_t after beam-constrained fit	$\geq$	20 GeV
Track-Stub matching in R-ϕ	$<$	10 cm
$E_{\rm EM}$ in muon tower	$<$	2.0 GeV
$E_{\rm HAD}$ in muon tower	$<$	6.0 GeV
$E_{\rm T}(\Delta R < 0.4) - E_{\rm T}(\Delta R < 0.13)$	$<$	5 GeV
D_0 of matching CTC track	$<$	0.5 cm
Δz of matching CTC track	$<$	5.0 cm

Table 1: Cuts used to select the high p_t data sample.

CMCOSM also uses information from the Hadron TDC's. The energy deposition of a muon is near the Hadron TDC threshold, especially for cosmic ray tracks which often cross tower boundaries. Combined with the poor time resolution at low energy deposition, we found that the Hadron TDC's were too unreliable to use as a flagger. However, figure 5 shows that they provide a nice cross check. The figure shows the time-of-flight ($t_{bottom} - t_{top}$) of a particle across the detector, which peaks at about 20 nS for the events flagged as cosmic rays (solid histogram). Superimposed is the same time difference for events where there happens to be calorimeter activity at 180° from the muon candidate, peaking at 0 nS. The 2 events flagged as cosmics but having time-of-flight less than 10 nS were previously identified as misflagged $p\bar{p}$ events [1].

(2) Electron samples

The electron W and Z samples provide another check. We ran the filter on a standard $W \rightarrow e\nu$ data sample [2], with the electron track as the cosmic ray test track. Of 1520 events with the electron in the central muon fiducial region, having $p_t > 15$ GeV, and passing the CTRSEL track quality requirements, 2 were flagged as cosmic rays. These were mis-flagged due to low quality ("fake") tracks back-to-back with the electron. We also ran the flagger on a standard $Z^\circ \rightarrow e^+e^-$ sample, requiring that the electrons have $|\eta| < 1.1$, and lost 1 event because the 2^{nd} track was poorly reconstructed.

(3) Another flagger

Finally, a more sophisticated back-to-back algorithm is under development. In addition to $\Delta\phi$ information and $\Delta\eta$ information for pairs of 3D tracks, this method also compares the curvature of the two legs, weighting by the calculated errors $\delta\phi$, $\delta(ctn\theta)$, $\delta(crv)$ in the track parameters. W and Z events are simple and our

[1] The two run/event numbers are 20007/21925 and 17548/3213. The second fails the isolation cut.

[2] See CDF-1166.

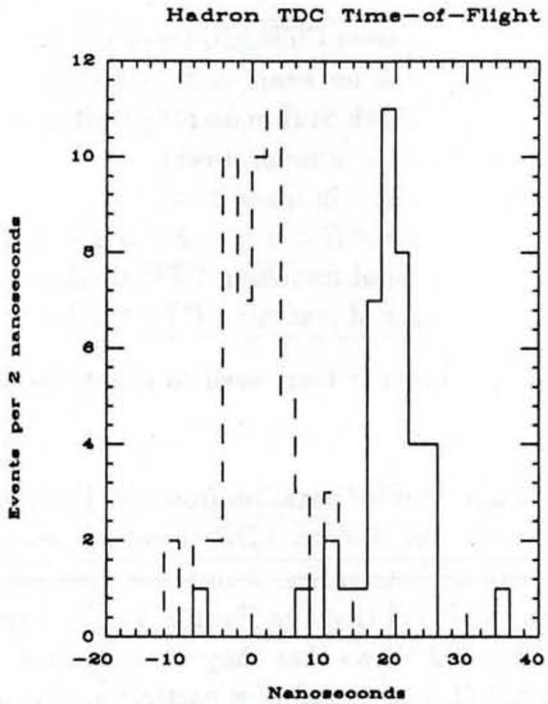

Figure 5: Hadron TDC time-of-flight. The solid histogram is for those events flagged as cosmic rays. The dashed histogram is for the events not flagged as cosmics.

simple algorithm suffices, but for future analyses in more complex environments (or perhaps even for W/Z studies when the instantaneous luminosity is high enough that most events have multiple $p\bar{p}$ interactions) this more subtle approach will perhaps be the "right" method.

4. Summary

The routine C$MUO:CMUCOS.CDF has been shown to be 99.8% efficient for W and Z muon events while leaving less than 0.4% cosmic background contamination.

Note that muons from K/π-decay [3] or non-interacting pions [4] were not considered background but as a real signal from the beam-beam interaction. These should either have a separate filter or be included in the background estimates.

References

1. A. Byon and A. Para, "CTC Track Selection", CDF-570.
2. M. Binkley and J. Yun, "C$DOC:DAISVTVZ.MEM"
3. J. Skarha, "K/π decay in CTC", CDF-587.

D.A. Smith and T. Westhusing, "Decay-in-Flight Acceptance of the Central Muon Chambers", CDF-726.

4. D.A. Smith and H. Jensen, "Pion Punchthrough Probability in the Central Calorimeter", CDF-707.