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Top and ElectroWeak Event Classification Module for CDF Run II

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Abstract

Description of TopEventModule in the TopMods package. This module classifies events by the number of electrons, muons and jets and the amount of missing transverse energy. TopEventModule is the standard method of the Top and ElectroWeak physics groups for the selection of event samples.

1 Introduction

TopEventModule is the standard method of the Top and ElectroWeak physics groups for the selection of event samples and the classification of electrons, muons, jets and missing transverse energy. A standard event selection and object classification simplifies the comparison of physics analyses, *e.g.* a standard definition of the electron selection variables and cut values for the comparison of the $Z \rightarrow e^+e^-$ cross-section with the $W \rightarrow e\nu$ cross-section.

TopEventModule is an AC++ module and uses the AC++ Run II objects. In an event, objects that pass selection cuts are saved in the event record, either as a list of objects (a collection) or as a list of pointers to objects (a view). The description prefix of these new objects can be specified by the user via talk-to newTopCollectionPrefix. There are two levels of selection cuts, tight and loose. Note there is no overlap between tight and loose objects: a loose object must have failed the tight cuts. **TopEventModule** classifies events based on the number of tight and loose electrons, muons, jets and the amount of missing transverse energy. The event classification is stored in a **TopSummary** object that is saved in the event record.

Note that there are more tight lepton types (CEM, PEM, CMUP, CMX, CMU, CMP, BMU) than lepton triggers (CEM, CMUP, CMX). You need to check that at least one of the tight leptons is of trigger type. If you want to just filter events, you can use **TopFilter** to do this. If you want to keep all the events in a ntuple, then you must remember to check the tight lepton type in your analysis code.

TopFilter uses the **TopSummary** object information to filter events. The user can specify the number of tight/loose jets, electrons, muons, the amount of MET, $\sum E_T$ of jets, and the tight lepton type.

For further analysis, other AC++ Run II modules can be run after TopEventModule and TopFilter, *e.g.* the SecVtxModule can look for b-tags in the TopEventModule tight jet collection. The user can also run their favorite ntuple-making module, *e.g.* TopNtuple or Stntuple with the descriptions of the tight and loose objects given in a talk-to.

Instructions on how to use TopEventModule in the latest offline release can be found at this web page [1]. The following sections describe the determination of the event z position, the selection of electrons, muons and jets, the calculation of the missing transverse energy, the classification of the event, the TopSummary object and the filter parameters.

2 Example tcl files

There are example tcl files in the TopMods/test area. topevent.tcl is the main one and has simple talk-to's for TopEventModule, TopFilter and TopNtuple. TopCheckModule and topcheck.tcl are just a simple check that reads in the new TopEventModule objects and prints them out.

Here is an example TopEventModule talk-to that sets up the Run II analysis cuts:

```
    module talk TopEventModule
        #prefix for new objects
         newTopCollectionPrefix set MyTop
        #Use Run II analysis lepton id cuts
         leptonIdCuts set 2
        #Use max Et lepton z0
         eventZPosition set 2
        #User must set CalData process name
         jets
             calDataProcessName set PROD
         exit
         printLevel set 1
         parmSetName set TopEvent
exit
```

Here is an example TopFilter talk-to that keeps events with at least 1 tight lepton in CEM, CMUP or CMX and at least 2 tight jets and vetos cosmics:

```
    module talk TopFilter
        #prefix of summary object
         newTopCollectionPrefix set MyTop
         nTightJets set 2
         nTightLeptons set 1
        #OR of tight lepton types
         nTightCEM set 1
         nTightCMUP set 1
         nTightCMX set 1
        #Veto cosmics
         CosmicSel set 2
```

```
        printLevel set 0
        show
exit
```

3 Main Menu

Here is quick description of the top level menu of TopEventModule.

- **newTopCollectionPrefix:** The user can change the prefix of the TopEventModule objects. The descriptions of the new objects are: XXXSummary, XXXTightEmObjectView, XXXLooseEmObjectView, XXXTightMuonView, XXXLooseMuonView, XXXTightJetView, XXXLooseJetView, XXX_JETCLU0.4_ReclusterJetColl and XXXMetCorrected (vertex only), where XXX means the value of newTopCollectionPrefix and JETCLU0.4 is the name and cone size for the jet clustering algorithm. You can use the command "Edm_ObjectLister -n 5 yourFileName" to see a data file's objects and their descriptions. For your own private studies, avoid using the two prefixes used in the official top group datasets: *Inclusive* for the inclusive high p_T lepton; *WZ* for the Run II W/Z datasets.
- **leptonIdCuts:** Option to use hardwired values for electron and muon identification cuts. The cut values are printed out at BeginJob. Note that *show* in the tcl file will not show these values. Also beware that any talk-to's you set in the electron or muon menu will be overwritten by the hardwired values. For example, if in your tcl file you have *leptonIdCuts set 2* and on the electron tight sub menu *eleEtCut set 13.0*, the hardwired value of 20.0 GeV will be used for the electron E_T cut, not your value of 13.0.

  0. no hardwired cuts - set lepton id cuts in tcl file with electron and muon talk-to menus.
  1. W/Z analysis Run I-like lepton cuts [10].
  2. W/Z analysis Run II lepton cuts used by Top Group [11].
  3. Run II inclusive high p_T lepton dataset cuts
  4. W/Z analysis Run II lepton cuts without isolation or $|z_0|$ cut

- **eventZPosition:** Vertex strategy for reclustering jets and recalculating MET. Described in the next section.
- **performEleSel, performMuonSel, performJetSel, performZSel, performWSel, performCosmicSel:** Catastrophic error switches that allow you to switch off parts of the code! You should never need to change these.
- **mcBeamXPos, mcBeamYPos, mcBeamXSlope, mcBeamYSlope, mcBeamXWidth, mcBeamYWidth:** Allows you to set the beam position and slope so that you can use beam constraint tracking with Monte Carlo.
- **printLevel:** Print suppression. -2 will print nothing. The default -1 will print out summary information at the end of the job. This consists of five tables: a summary of the number of events with tight/loose leptons, Z and W bosons, and tight jets; two tables classifying

events according to W, jet and lepton multiplicity; another two tables showing the number and percentage of defEmObjects and defMuons that failed each of the selection cuts. 0 will also print out a summary for each event. 1 will also print out the cutCode for electrons, muons and jets. 2 will also print out the values of the cut variables. 3 will also print out lots of information about the jet relustering.

4 Event z position

For the jet reclustering and the missing transverse energy calculation, the user can control the definition of the event z position with the talk-to eventZPosition, which has five possible values, listed below. This z position is available from TopSummary object with accessor jetZVertex().

0. nominal origin at 0.0 cm
1. Good quality ($\geq$ 12) highest p_T vertex from ZVertexColl [3]. If no good quality vertex, fall back to any quality.
2. z_0 of the tight lepton with the highest transverse energy (default for summer 2003)
3. Good quality ($\geq$12) ZVertexColl vertex closest to z_0 of the tight lepton with the highest transverse energy
4. average of z_0 of the tight leptons
5. Same as 3 but if no tight isolated lepton, use tight non-isolated leptons instead
6. Same as 2 but if no tight isolated lepton, use tight non-isolated leptons instead

If the chosen option, n, is undefined in an event, *e.g.* no tight lepton found, then the next logical option is used. For instance, the default is to use option 2, the z0 of the highest transverse energy tight lepton. If there is no tight lepton, then option 1 is used instead. If there is no primary vertex then option 0 is used, the nominal origin.

Options 5 and 6 were added to make treatment of non-isolated leptons and isolated leptons more similar, in order to aid cross-checks for SECVTX b-tag studies and non-W background estimates.

Option 5 was adopted for the summer 2003 b-tag analyses, since the ZVertexColl object uses many tracks and so is a more precise determination of the event z position. This is important for seeding the primary vertex finder, PrimeVtx [4], which only uses tracks within $\pm$1cm of the event z position! However, for W and Z events with low track multiplicity, it needs some more study.

5 Electron Menu

The AC++ class for electrons, and photons, is called CdfEmObject [5]. A CdfEmObject always contains a link to the EM calorimeter cluster object, EmCluster, and may contain links to a matched charged particle track and matched clusters in the Shower Maximum chambers.

The reconstruction code provides a default list of CdfEmObjects via the method *defEmObjects()*. Each CdfEmObject from the default list that passes a tight selection is added to a CdfEmObjectView with description *XXXTightEmObjectView*, where XXX means your choice for the newTopCollectionPrefix. Any CdfEmObject that fails the tight selection but passes a loose selection is added to a CdfEmObjectView with description *XXXLooseEmObjectView*. Note that tight and loose electrons are exclusive. The number of tight and loose electrons and links to the views are stored in a TopSummary object.

The electron menu in TopEventModule has two sub-menus that allow you to set tight and loose cuts. The next subsections describe the selection variables for electrons in the Central calorimeter and in the Plug calorimeter. These references are preliminary studies of electrons in Run II [6, 7, 8, 9].

5.1 Reconstruction Options

The definition of some of the selection variables can be changed with these reconstruction options. The corrected/constrained values for the calorimeter energy and track momentum are then used consistently to calculate the selection variables like transverse energy and E/p. All of these corrections are done in Top/src/TopAlgorithms.cc method correctElectrons(...).

- **CEM mapping correction - eleCemCorr:** Option to apply the CEM mapping energy corrections. Note that a CES cluster seeded by matched track is required.
  `CemCorrAlg::GetCemCorr( emObject, "USETRACK", cemMapCorr)`
- **CEM Tower-to-Tower correction -eleCemTowerCorr:**The CEM tower-to-tower corrections should not be applied for MC, or for data processed with 4.8.4 and later since the corrections are already applied in Production.
  `TopAlgorithms::GetCemTowerCorr(emObject,cemTowerCorr)`
- **CEM Number of Towers -eleNumberOfTowers:** Electron four-momentum can be calculated with 3 or 2 towers. Note the 2 tower option requires a matched track to determine the closest neigbour tower. `corrVec = emobj_alg::CEMFourMomentum::TwoTower(emObject,useTrack)` or `corrVec = emobj_alg::CEMFourMomentum::ThreeTower(emObject,useTrack)`
- **COT Parent - eleUseCotParent:** True means use the COT parent of the best matched track. If there is no COT parent (roughly 2% of electron matched tracks seem to be standalone in 4.8.4), then use the COT parent of the next highest pt matched track (from collection `emObject.matchingTracks()`). If there is still no COT parent, then the track link is set to null, so that all track-related cuts will fail.
- **Beam constraint - eleBeamConstraint:** Option to add the beam spot constraint to the COT track fit, in order to improve the measurement of the electron transverse momentum. Only applied to tracks with no silicon hits.

5.2 Central Calorimeter Electrons

These are the selection variables for CdfEmObjects in the central calorimeter, i.e. EmCluster region is CEM. The default values and talk-to names for the tight cuts are listed in Table 1 and for the loose cuts in Table 3. The values from the Run 1 "lepton+jets" channel [10] are also listed and can be set via the talk-to leptonIdCuts set 1. The values from the Run 2 "lepton+jets" channel [11] are also listed and can be set via the talk-to leptonIdCuts set 2.

- **EM Transverse energy - eleEtCut:** The best estimate of the electron Et.
- **eleEmEtCeiling:** Cuts on Had/Em, Lshr and E/p are not applied for electrons with EM E_T above this value.
- **Transverse momentum - eleBelowEmEtCeilingPtTrackCut, eleAboveEmEtCeilingPtTrackCut:** p_T of best track associated with the CdfEmObject, `emObject.maxPtTrack()`;
- **Had/EM energy - eleHadEmConst, eleHadEmLin:** The ratio of the hadronic calorimeter energy to the electromagnetic calorimeter energy using all towers included in the EmCluster `emCluster->hadEm()`. The cut is $h < a + b * E$ where h is the ratio, a, b are constants specified by talk-to's and E is the EM calorimeter energy in GeV. Note no cut is made for electrons with EM E_T above a threshold given by talk-to eleEmEtCeiling.
- **Lshr - eleLshrCut:** Quality of the match of the energy sharing in the three tower EmCluster with that expected for an electron, `emobj_alg::CalculateLshr::lshr(*emCluster, strip_cluster->fitted_position(),emTrack->z0(),nTower)` Note no cut is made for electrons with EM E_T above a threshold given by talk-to eleEmEtCeiling.
- **eleEPCeiling:** No cut on E/P for electrons with p_T above this value.
- **E/p - eleEPMaxCut, EleEPMinCut:** EM calorimeter energy divided by the momentum of the maximum p_T matched track. Note no cut is made for electrons with EM E_T above a threshold given by talk-to eleEmEtCeiling or with p_T above talk-to eleEPCeiling.
- $|\mathbf{z_0} - \mathbf{z_{vtx}}|$ **- eleDeltaZVertexCut:** Distance between z_0 of the maximum p_T matched track and the z position of the highest p_T vertex from ZVertexColl (available from TopSummary object with accessor primaryZVertex()).
- $|\mathbf{z_0}|$ **- eleZ0Cut:** Distance between z_0 of the maximum p_T matched track and the origin
- $|\mathbf{z_{vtx}}|$ **- eleZVertexCut:** Distance between the z position of the highest p_T vertex from ZVertexColl (available from TopSummary object with accessor primaryZVertex()) and the origin.
- **Track isolation - eleTrackIsolCut:** Total excess transverse momenta (i.e. excluding maximum p_T matched track) of all tracks within a cone of radius $\Delta R = 0.4$ and within 5 cm of the maximum p_T matched track z_0, divided by the transverse momentum of the maximum p_T matched track.
- **Axial segments - eleNCotAxialSegCut:** Number of track segments with at least 6 hits in the COT axial superlayers for the maximum p_T matched track.
- **Stereo segments - eleNCotStereoSegCut:** Number of track segments with at least 6 hits in the COT stereo superlayers for the maximum p_T matched track.
- **Axial hits - eleNCotAxialHitCut:** Number of track hits in the COT axial superlayers for the maximum p_T matched track.
- **Stereo hits - eleNCotStereoHitCut:** Number of track hits in the COT stereo superlayers for the maximum p_T matched track.

- **Matched CES cluster - eleShowerMaxMatch:** True means want to apply cuts on CES strip and wire clusters and electron will fail cuts if there is not a matched CES cluster. False means CES strip and wire cuts will not be applied and electron will pass. Clusters are defined by `emObject.bestMatchingCesCluster(CesCluster::STRIP,"TRACK")` and `emObject.bestMatchingCesCluster(CesCluster::WIRE,"TRACK")` accessors.

- **$|\Delta z|$ - eleDeltaZCut:** Distance between the z position of the best matching CES strip cluster, `strip_cluster->globalCoord()` , and the z position of the extrapolation to the CES of the maximum p_T matched track, `emobj_alg::TrackLocalCoord::vect(emObject,emTrack).z()`. This is corrected for CES-COT misalignment.

- **$Q * \Delta x$ - eleNegDeltaXCut, elePosDeltaXCut:** Distance, signed by the track charge, between the x position of the CES wire cluster `wire_cluster->localCoord()` , and the x position of the extrapolation to the CES of the maximum p_T matched track, `emobj_alg::TrackLocalCoord::vect(emObject,emTrack).x()`. This is corrected for CES-COT misalignment.

- **CES strip χ^2 - eleStripChi2Cut:** Quality of the match of the shower shape for the best matching CES strip cluster with that expected for an electron. `scaleCesChisq(strip_cluster->chi2(), Energy);`

- **Fiducial - eleFiducial:** Within fiducial volume of CEM tower, but not in tower 9 or in chimney tower 7, (FIDUCIAL_CEM from `fidEle(emObject)`). Note that a matched CES strip cluster and a matched CES wire cluster are required.

- **Conversion - eleConversionVeto:** Value of 1 means electron if consistent with coming from a photon conversion. Conversions are opposite sign electron-track pairs with similar directions (eleConversionLambdaCut) and small separation in the x-y plane (eleConversion-SepCut). Trident events, where electron has radiated a photon which then converts, are flagged by -2 and kept as good electrons.

- **Isolation - eleIsolCut:** Total excess energy (i.e. excluding electron towers) within a cone of radius $\Delta R = 0.4$ about the EmCluster centroid, divided by the electron transverse energy. Corrected for leakage if electron is near tower boundary - needs CES wire cluster. `(emCluster->totalIsolationEt4() - leakE) / Et` where leakage correction is from `IsoCorrAlg::GetIsoCorr( emObject, leakE, "USETRACK")`.

- **Isolation Energy - eleIsolEnergyCut:** Total excess energy (i.e. excluding electron towers) within a cone of radius $\Delta R = 0.4$ about the EmCluster centroid.

5.3 Plug Calorimeter Electrons

These are the selection variables for CdfEmObjects in the plug calorimeter, i.e. EmCluster region is PEM. However, as of June 2003, no PEM electron is allowed to be a tight electron. In a future release based on 5.1, the Phoenix electron cuts will be added and the default cuts will be revised accordingly.

Central Electron Variable	Talk-to name	Run I	Run II	Inclusive
E_T (GeV)	eleEtCut	20.0	20.0	18.0
$*$ Had/EM Energy, constant term	eleHadEmConst	0.05	0.055	0.125
$*$ Had/EM Energy, linear term	eleHadEmLin	-	0.00045	-
$*$ Lshr	eleLshrCut	0.2	0.2	0.3
p_T (GeV/c)	eleBelowEmEtCeilingPtTrackCut	10.0	10.0	9.0
p_T (GeV/c)	eleAboveEmEtCeilingPtTrackCut	-	-	15.0
$*$ E/p max	eleEPMaxCut	1.5	2.0	4.0
$*$ E/p min	eleEPMinCut	-	-	-
$\|z_0 - z_{vtx}\|$ (cm)	eleDeltaZVertexCut	-(5.0)	-	-
$\|z_0\|$ (cm)	eleZ0Cut	-	60.0	-
$\|z_{vtx}\|$ (cm)	eleZVertexCut	-	-	-
Track isolation	eleTrackIsolCut	-	-	-
Axial Segments	eleNCotAxialSegCut	-	-	-
Stereo Segments	eleNCotStereoSegCut	-	-	-
Axial Hits	eleNCotAxialHitCut	-	-	-
Stereo Hits	eleNCotStereoHitCut	-	-	-
Matched CES cluster	eleShowerMaxMatch	Yes	Yes	Yes
$\|\Delta z\|$ (cm)	eleDeltaZCut	3.0	3.0	5.0
$Q * \Delta x$ (cm)	eleNegDeltaXCut	-1.5	-3.0	-3.0
$Q * \Delta x$ (cm)	elePosDeltaXCut	1.5	1.5	3.0
CES strip χ^2	eleStripChi2Cut	10.0	10.0	-
Fiducial	eleFiducial	Yes	-	-
Conversion	eleConversionVeto	- (Yes)	-	-
Isolation	eleIsolCut	0.1	0.1	-
Isolation E (GeV)	eleIsolEnergyCut	-	-	-
Em E_T, ceiling	eleEmEtCeiling	-	-	70.0
p_T, ceiling	eleEPCeiling	-	50.0	-
CEM mapping correction	eleCemCorr	Yes	Yes	No
Number of Towers	eleNumberOfTowers	2	2	3
COT parent	eleUseCotParent	Yes	Yes	No
Beam Constraint	eleBeamConstraint	Yes	Yes	No
Conversion (rad)	eleConversionLambdaCut	0.04		
Conversion (cm)	eleConversionSepCut	0.2		

Table 1: The default values for the tight CEM electron selections for Run I analysis cuts, Run II analysis cuts and Run II inclusive high p_T cuts. $*$ indicates that the cut is not applied if the EM transverse energy is above a threshold given by eleEmEtCeiling.

- **Transverse energy - elePlugEtCut:** This uses the energy and direction of the EM calorimeter cluster, where the z position is taken as that of the the highest p_T good quality ZVertexColl object. The direction of any matched track is not used. The PEM face correction is used `PemCorrAlg::GetPemCorr( emObject, pemMapCorr)`.
- **Had/EM energy - elePlugHadEmConst, elePlugHadEmLin:** The ratio of the hadronic calorimeter energy to the electromagnetic calorimeter energy using all towers included in the EmCluster `emCluster->hadEm()`. The cut is $h < a + b * E$ where h is the ratio, a, b are constants specified by talk-to's and E is the EM calorimeter energy in GeV. Note no cut is made for electrons with EM E_T above a threshold given by talk-to elePlugEmEtCeiling.
- $\chi^2_{\mathbf{3x3}}$ **- elePlugChi2Cut:** Quality of match of energy sharing in a 3x3 tower grid centred on the seed tower with that expected for an electron [12], `emCluster->pem3x3Chisq()`.
- **Matched PES cluster - elePlugShowerMaxMatch:** True means want to apply cuts on PES 2D clusters and electron will fail cuts if there is not a matched PES cluster. False means PES cuts will not be applied and electron will pass. CdfEmObject has matched PES 2D clusters.
- $\mathbf{\Delta R}$ **- elePlugDelRCut:** Distance, $\sqrt{\Delta\eta^2 + \Delta\phi^2}$, between the PEM cluster and the best matching PES cluster.
- **PES U 5-by-9 Profile - elePlugU5by9Cut:** Value of 5by9 profile ration in U view, `pesClusterU().pesProfileRatio5by9()`.
- **PES V 5-by-9 Profile - elePlugU5by9Cut:** Value of 5by9 profile ration in V view, `pesClusterV().pesProfileRatio5by9()`.
- **Fiducial - eleFiducial:** Within fiducial volume of PEM, `fidEle(emObject)` result FIDUCIAL_PEM). Note that a matched PES 2D cluster is required.
- **Isolation - elePlugIsolCut:** Total excess energy (i.e. excluding electron towers) within a cone of radius $\Delta R = 0.4$ about the EmCluster centroid, divided by the electron transverse energy. Corrected for leakage if electron is near tower boundary - needs PES 2d cluster. `(emCluster->totalIsolationEt4() - leakE) / Et` where leakage correction is from `IsoCorrAlg::GetIsoCorr( emObject, leakE, "USETRACK")`.
- **Isolation Energy - elePlugIsolEnergyCut:** Total excess energy (i.e. excluding electron towers) within a cone of radius $\Delta R = 0.4$ about the EmCluster centroid.

6 Muon Menu

The AC++ class for muons is called CdfMuon [13, 14, 15]. A CdfMuon contains a list of muon stubs, a link to the best track match, information about the track-stub match, and calorimeter and isolation data.

The reconstruction code provides a default list of CdfMuons via the method *defMuons()*. Each CdfMuon from the default list that passes a tight selection is added to a CdfMuonView with

Plug Electron Variable	Talk-to name	Run II	Inclusive
E_T (GeV)	elePlugEtCut	20.0	20.0
$*$ Had/EM Energy, constant term	elePlugHadEmConst	0.05	0.1
$*$ Had/EM Energy, linear term	elePlugHadEmLin	-	-
χ^2_{3x3}	elePlugChi2Cut	10.0	-
Matched PES cluster	elePlugShowerMaxMatch	Yes	No
$\|\Delta R\|$ (cm)	elePlugDelRCut	0.05	-
U5by9	elePlugU5by9Cut	0.65	-
V5by9	elePlugV5by9Cut	0.65	-
Fiducial	eleFiducial	-	-
Isolation	elePlugIsolCut	0.1	0.1
Isolation E (GeV)	elePlugIsolEnergyCut	-	-
Em E_T, ceiling	elePlugEmEtCeiling	-	100.0

Table 2: As of June 2003, no PEM electron is allowed to be a tight electron. In a future release based on 5.1, the Phoenix electron cuts will be added and the default cuts will be revised accordingly. $*$ indicates that the cut is not applied if the EM transverse energy is above a threshold given by elePlugEmEtCeiling.

Electron Variable	Talk-to name	Loose cut
E_T (GeV)	eleEtCut	20.0
p_T (GeV/c)	eleBelowEmEtCeilingPtTrackCut	10.0
E_T (GeV)	elePlugEtCut	20.0

Table 3: The default values for the loose CEM and PEM electron selections. The cut values are the same for Run I analysis cuts, Run II analysis cuts and Run II inclusive high p_T cuts. The reconstruction options are the same as for tight electrons in each case.

description *Top TightMuonView*. Any CdfMuon that fails the tight selection but passes a loose selection is added to a CdfMuonView with description *TopLooseMuonView*. Note that tight and loose muons are exclusive. The number of tight and loose muons and links to the views are stored in a TopSummary object.

The muon menu in TopEventModule has two sub-menus that allow you to set tight and loose cuts. The next subsections describe the selection variables for muons. These references are preliminary studies of muons in Run II [16, 17, 18].

6.1 Reconstruction Options

The definition of some of the selection variables can be changed with this reconstruction options. The constrained value for the track momentum is then used consistently to calculate the selection variables like transverse momentum and z_0. All of these corrections are done in Top/src/TopAlgorithms.cc method correctMuons(...).

- **COT Parent - eleUseCotParent:** True means use the COT parent of the best matched track. If there is no COT parent then the track link is set to null, so that the muon will fail the cuts.
- **Beam constraint:** Option to add the beam spot constraint to the COT track fit, in order to improve the measurement of the electron transverse momentum. Only applied to tracks with no silicon hits.

6.2 Muons

These are the selection variables for CdfMuons. The default values for the tight cuts are listed in Table 4 and for loose cuts in Table 5. The values from the Run I "lepton+jets" channel [10] are also listed and can be set via the talk-to leptonIdCuts set 1. The values from the Run 2 "lepton+jets" channel [11] are also listed and can be set via the talk-to leptonIdCuts set 2.

- **Transverse momentum - muonPtCut:** Transverse momentum of CdfMuon best matched track.
- **Had Energy - muonHadConst, muonHadLin:** Hadronic energy in the calorimeter towers traversed by muon. The cut value increases for muons with momenta, p, above 100.0 GeV/c as $a + b * (p - 100.0)$, where a, b are constants.
- **Em Energy - muonEmConst, muonEmLin:** Electromagnetic energy in the calorimeter towers traversed by muon. The cut value increases for muons with momenta, p, above 100.0 GeV/c as $a + b * (p - 100.0)$, where a, b are constants. (Changed in 4.6.0int2 from p_T to p.)
- **Had+Em Energy - muonEmHadCut:** Sum of hadronic and electromagnetic energy in the calorimeter towers traversed by muon.
- $|\mathbf{z_0 - z_{vtx}}|$ **- muonDeltaZVertexCut:** Distance between z_0 of the best matched track and the z position of the highest p_T vertex from ZVertexColl (available from TopSummary object with accessor primaryZVertex()).
- $|\mathbf{z_0}|$ **- muonZ0Cut:** Distance between z_0 of the maximum p_T matched track and the origin
- $|\mathbf{z_{vtx}}|$ **- muonZVertexCut:** Distance between the z position of the highest p_T vertex from ZVertexColl (available from TopSummary object with accessor primaryZVertex()) and the origin.
- $|\mathbf{d_0}|$ **- muonD0COT:** If track did not use Silicon hits, this cut is on the 2-D impact parameter of best matched track, with respect to COT beam spot position.
- $|\mathbf{d_0}|$ **- muonD0SVX:** If track did use Silicon hits, this cut is on the 2-D impact parameter of best matched track, with respect to SVX beam spot position.
- **Axial segments -muonNCotAxialSegCut:** Number of track segments with at least 6 hits in the COT axial superlayers for the best matched track.
- **Stereo segments - muonNCotStereoSegCut:** Number of track segments with at least 6 hits in the COT stereo superlayers for the best matched track.

- **Axial hits - muonNCotAxialHitCut:** Number of track hits in the COT axial superlayers for the best matched track.
- **Stereo hits - muonNCotStereoHitCut:** Number of track hits in the COT stereo superlayers for the best matched track.
- **Isolation - muonIsolCut:** Total excess energy (i.e. excluding muon towers) within a cone of radius $\Delta R = 0.4$ about the muon, divided by the muon transverse momentum.
- **Isolation Energy - muonIsolEnergyCut:** Total excess energy (i.e. excluding muon towers) within a cone of radius $\Delta R = 0.4$ about the muon.
- **Track isolation - muonTrkIsolCut:** Total excess transverse momenta (i.e. excluding best matched track) of all tracks within a cone of radius $\Delta R = 0.4$ and within 5 cm of the best matched track z_0, divided by the transverse momentum of the best matched track.
- **Δx - muonDxcmuCut, muonDxcmpcut, muonDxcmxCut, muonDxbmuCut:** Distance in $r\Delta\phi$ between the stub direction and the track extrapolation to the stub. There are four stub types for the four different muon detectors: CMU, CMP, CMX and BMU.
- **muonANDcmupCut:** True means muon has to pass AND of CMU and CMP delta x cuts. False means muon has to pass OR of CMU and CMP delta x cuts.
- **muonWantStubless:** Allow stubless muons. The stubless muon has to satisfy all other cuts but the dx stub cuts.

7 Jet Menu

The AC++ class for jets is called CdfJet [19]. The reconstruction code provides several jet collections. However, these jets are clustered assuming a z-vertex position of 0.0 cm and any electrons in the event are probably double-counted as jets.

TopEventModule can recluster the jets using the JETCLU, MIDPOINT and KTCLUS algorithms with the best event z position, as defined in section 2. Towers belonging to any tight electrons found in the event are removed. A subtlety of this is that for $Z \rightarrow e^+e^-$ events with one tight and one loose electron, the loose electron is still in the jet list. It is important to note that the correct process name for the CalData object must be given or no reclustered jets will be calculated [20].

The user can choose which jet algorithms and cone-sizes to run with the talk-to's **recluster-JetAlgorithmList** and **reclusterJetConeRadiusList**. Here is an example talk-to that runs JETCLU with two different cone sizes as well as KTCLUS and MIDPOINT:

```
jets
    calDataProcessName set PROD
   #the default
    reclusterJetAlgorithmList set JETCLU
    reclusterJetConeRadiusList set 0.4
   #the extras - add as many as you like!
```

Muon Variable	Talk-to name	Run I	Run II	Inclusive
p_T (GeV/c)	muonPtCut	20.0	20.0	18.0
Had Energy, constant term (GeV)	muonHadConst	6.0	6.0	9.0
Had Energy, linear term	muonHadLin	-	0.0280	0.0420
Em Energy, constant term (GeV)	muonEmConst	2.0	2.0	3.0
Em Energy, linear term	muonEmLin	-	0.0115	0.0140
Em+Had Energy (GeV)	muonEmHadCut	-	-	-
$\|z_0 - z_{vtx}\|$ (cm)	muonDeltaZVertexCut	-(5.0)	-	-
$\|z_0\|$ (cm)	muonZ0Cut	-	60.0	-
$\|z_{vtx}\|$ (cm)	muonZVertexCut	-	-	-
$\|d_0\|$ (cm)	muonD0COT	-	-	
$\|d_0\|$ (cm)	muonD0SVX	-	-	
Axial Segments	muonNCotAxialSegCut	-	-	-
Stereo Segments	muonNCotStereoSegCut	-	-	-
Axial Hits	muonNCotAxialHitCut	-	-	-
Stereo Hits	muonNCotStereoHitCut	-	-	-
Isolation	muonIsolCut	-	0.1	-
Isolation E (GeV)	muonIsolEnergyCut	-	-	-
Track isolation	muonTrkIsolCut	-	-	-
CMU $\|\Delta x\|$ (cm)	muonDxcmuCut	2.0	3.0	5.0
CMP $\|\Delta x\|$ (cm)	muonDxcmpCut	5.0	5.0	10.0
CMX $\|\Delta x\|$ (cm)	muonDxcmxCut	5.0	6.0	10.0
BMU $\|\Delta x\|$ (cm)	muonDxbmuCut	0.0	10.0	50.0
CMU AND CMP	muonANDcmupCut	No	Yes	No
Stubless	muonWantStubless	No	No	
COT parent	muonUseCotParent	Yes	Yes	No
Beam Constraint	muonBeamConstraint	Yes	Yes	No

Table 4: The default values for the tight muon selections for Run I analysis cuts, Run II analysis cuts and Run II inclusive high p_T cuts.

Muon Variable	Talk-to name	Loose cut
p_T (GeV/c)	muonPtCut	10.0
Had Energy, constant term (GeV)	muonHadConst	9.0
Had Energy, linear term	muonHadLin	0.0420
Em Energy, constant term (GeV)	muonEmConst	3.0
Em Energy, linear term	muonEmLin	0.0140
Stubless	muonWantAny	Yes

Table 5: The default values for the loose muon selection. The cut values are the same for Run I analysis cuts, Run II analysis cuts and Run II inclusive high p_T cuts. The reconstruction options are the same as for tight muons in each case.

```
        reclusterJetAlgorithmList add JETCLU
        reclusterJetConeRadiusList add 0.7
        reclusterJetAlgorithmList add KTCLUS
        reclusterJetConeRadiusList add 0.5
        reclusterJetAlgorithmList add MIDPOINT
        reclusterJetConeRadiusList add 0.4
exit
```

The reclustered jet collections are appended to the event record with description *Top_JETCLU0.4_ReclusterJetColl*. The first jet collection in the list is used to make Tight and Loose CdfJetViews. Each CdfJet that passes a tight selection is added to a CdfJetView with description *TopTightJetColl*. Any CdfJet that fails the tight selection but passes a loose selection is added to a CdfJetColl with description *TopLooseJetColl*. Note that tight and loose jets are exclusive. The number of tight and loose jets and links to the collections are stored in a TopSummary object.

These are the selection variables for CdfJets. The default values for the tight/loose cuts are listed in Table 6.

- **Transverse energy:** Uncorrected transverse energy of the jet.
- **Detector η:** Detector η of the jet.
- **Recluster Jets:** Option to recluster jets using the best event z position.
- **Remove Electrons:** Option to remove tight electron towers before reclustering jets. Recluster jets must be true for this to have any effect.
- **reclusterJetAlgorithmList:** Name of jet algorithm. Allowed values are JETCLU, MIDPOINT and KTCLUS. Other names will result in helpful error message about unrecognised jet algorithm name. This list must be the same length as reclusterJetConeRadiusList - if this is not true, then a helpful error message will be printed out and you won't find any jets!
- **reclusterJetConeRadiusList:**Cone size. This list must be the same length as reclusterJetAlgorithmList - if this is not true, then a helpful error message will be printed out and you won't find any jets!
- **calData process Name:** In order to recluster the jets, a CalData object is required. For Production purposes, the default name is UNDEF, so **you must specify the correct process name or the jets will not be reclustered.** Error messages will be in the log file and there will be no tight or loose jets, so it should be clear what has happened. The usual suspects for the process name are PROD, USRP and L3. If you are unsure what the process name is, try running this command on one of your input data files: *Edm_ObjectLister -n4 yourInputFileName*. This will list all the objects in the event record. One of the columns gives the process name and one of the entries should be CalData.

Jet Variable	Talk-to name	Tight cut	Loose cut
E_T (GeV)	jetTightEtCut/jetLooseEtCut	15.0	8.0
Detector η	jetTightEtaCut/jetLooseEtaCut	2.0	2.4
Recluster Jets	reclusterJet	Yes	
Remove electrons	removeTightElectronTowers	Yes	
Jet Cone Radius	reclusterJetConeRadius	0.4	
CalData process Name	calDataProcessName	UNDEF	

Table 6: The default values for the tight and loose jet selections. These should not be taken as the final values.

8 Hadronic variables

Five hadronic variables are calculated and stored in the TopSummary object for the all-hadronic $t\bar{t}$ selection. They are the total transverse energy of the tight jets, the total transverse energy of the third-eighth tight jets, sphericity, aplanarity and centrality, $\sum E_T/\sqrt{\hat{s}}$.

9 Missing Transverse Energy

The AC++ class for the Missing Transverse Energy (MET) is called CdfMet [21]. The reconstruction code provides a CdfMet object that calculated with an event z position of 0.0 cm. Any muons in the event are not accounted for.

TopEventModule recalculates the MET with the best event z position, as defined in section 2, and with a correction for any tight muons, using beam-constrained track if desired (p_T subtracted and E_T in towers traversed by muon added). The magnitude and azimuthal angle of the default MET, vertex corrected MET and muon corrected MET are stored in the TopSummary object. The vertex corrected MET is also appended with description *TopMetCorrected*. To avoid inconsistencies between CdfMet accessors, the muon corrected MET is not appended. For instance, the missing energy components would not be consistent with sum of the components in each annulus of the calorimeter.

10 Event classification

There is a basic event classification for W, Z and $t\bar{t}$ events. The classification is stored explicitly for Z and $t\bar{t}$ candidates in the TopSummary object. **Note well that the dilepton, lepton + jets or all-hadronic $t\bar{t}$ classifications are mutually exclusive.** The classification does not represent all the final cuts, *e.g.* certain kinematic cuts are obviously not implemented for the dileptons.

Note well that the event classification word stored in the TopSummary object is a bit-mask. This means you should check the individual bits, not the integer value of the word. User-friendly accessors are provided, but if you feel you have to decode it yourself, this reference shows you what the values are [22]. You can use the masks DIL_MASK, LJ_MASK, HAD_MASK, Z_MASK, W_MASK and COSMIC_MASK defined there.

- **Cosmic:** If there is a CosmicRayInfo object with hasCosmicRay() true. You have to either have a PROD CosmicRayInfo object or to make your own by running CosmicRayFinder-Module before TopEventModule.
- **W boson:** If there is at least one tight electron or muon and the MET is above a threshold, the event is classified as containing a W boson. The default MET threshold is 20 GeV.
- **Z boson veto:** If the Z boson veto code has a electron-defEmobject, electron-EmJet, electron-track, muon-defMuon, muon-defStublessMuon, muon-track pair with invariant mass within a mass window, the event is classified as containing a Z boson. The default mass window is $[76, 106]$ GeV/c^2. Some extra bits are set to indicate which pairing flagged the event as a Z boson.
- **$\mathbf{t\bar{t}}$ dilepton**: If there are at least 2 tight leptons, at least 2 tight jets and the MET is above a threshold, the event is classified as a dilepton $t\bar{t}$ candidate. The default MET threshold is 20 GeV.
- **$\mathbf{t\bar{t}}$ lepton + jets**: If there is exactly 1 tight lepton, at least 3 tight jets and the MET is above a threshold, the event is classified as a lepton + jets $t\bar{t}$ candidate. The default MET threshold is 20 GeV.
- **$\mathbf{t\bar{t}}$ all-hadronic**: If there are no tight leptons, and at least 4 tight jets, the event is classified as an all-hadronic $t\bar{t}$ candidate.

11 TopSummary object

The TopSummary object was carefully constructed by Ken Bloom. Therefore, it has a print method, links to the TopEventModule objects and user-friendly accessors.

- int eventCode() - event classification
- bool isDilepton() - equivalent to (eventCode() & 0x00000001 != 0)
- bool isLeptonJets() - equivalent to (eventCode() & 0x00000002 != 0)
- bool isAllHadronic() - equivalent to (eventCode() & 0x00000004 != 0)
- bool isZ() - equivalent to (eventCode() & 0x00000008 != 0)
- bool isW() - equivalent to (eventCode() & 0x00000010 != 0)
- bool isCosmic() - equivalent to (eventCode() & 0x00000020 != 0)
- int nTightEle()
- int nTightMu()
- int nTightJet()
- int nTightLepton()

- int nLooseEle()
- int nLooseMu()
- int nLooseJet()
- int nLooseLepton()
- float rawMissingEt()
- float rawMissingEtPhi()
- float vertexCorrMissingEt()
- float vertexCorrMissingEtPhi()
- float muonCorrMissingEt()
- float muonCorrMissingEtPhi()
- float leptonZVertex() - only used in lepton selection cut $|z_0 - z_{vtx}|$
- float jetZVertex() - used as event z position for jet and MET calculation
- float hadSumEt()
- float hadSumEt3()
- float hadCentrality()
- float hadAplanarity()
- float hadSphericity()
- int recoFlag() - stores some of TopEventModule's reco options

12 TopFilter

TopFilter has taken over the filter menu from TopEventModule. Events which pass the filter are written to an output data file for further analysis. The filter talk-to parameters are all zero by default, so every event passes. There are three types of filter talk-to parameters:

- Keep events with at least this number of objects:
  - nTightElectrons
  - nLooseElectrons
  - nTotalElectrons
  - nTightMuons
  - nLooseMuons
  - nTotalMuons

- nTightLeptons
- nLooseLeptons
- nTotalLeptons
- nTightJets
- nLooseJets
- nTotalJets
- exclusiveTightLeptons - true changes “at least” to “exactly”
- exclusiveTightElectrons
- exclusiveTightMuons
- exclusiveTightJets
- exclusiveLooseJets
- exclusiveTotalJets

- Keep events with at least one of the following (an OR is performed)
  - nTightCEM
  - nTightPEM
  - nTightCMUP
  - nTightCMX
  - nTightCMU
  - nTightCMP
  - nTightBMU
- Keep events with at least this amount of MET/energy:
  - MissingEt
  - sumEtJets
  - sumEtTightJets
- Keep (value=1) or veto (value=2) events with a Z or W boson:
  - ZbosonSel - very loose for Z boson removal
  - WbosonSel
  - CosmicSel

For example if you want to keep events with at least 1 tight lepton, at least 2 tight jets and more than 20 GeV of missing transverse energy, you should

13 TopNtuple

TopNtuple is a public ntuple available for group use. It is described in a separate note [25].

14 Conclusions

TopEventModule is a module designed to classify events based on the number of leptons, jets and amount of MET. This information is stored in a TopSummary object. TopFilter uses the TopSummary object to filter events.

Future improvements for 5.x version will include Phoenix electron selection, option to apply jet and MET corrections, real dilepton veto and trigger information in TopSummary for faster checking.

References

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[18] Muon Group web page.
`http://www-cdf.fnal.gov/upgrades/computing/projects/reconstruction/muon/muon_software.html`

[19] CdfJet documentation.
`http://cdfcodebrowser.fnal.gov/CdfCode/source/JetObjects/doc/JetObjectsDoc.html`

[20] Usual process names for CalData are PROD, L3 or USRP. See hints at `http://cdfcodebrowser.fnal.gov/CdfCode/source/TopMods/doc/documentation.html`

[21] CdfMet documentation.
`http://cdfcodebrowser.fnal.gov/CdfCode/source/MetObjects/doc/MetDoc.html`

[22] The TopSummary event classification masks and accessors can be found at
`http://cdfcodebrowser.fnal.gov/CdfCode/source/TopObjects/TopObjects/TopSummary.hh`
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