DØ Collaboration

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Content of the p17 Muon Thumbnail

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Abstract

This document describes the MuonParticle objects stored in the p17 muon thumbnail. Based on DØNote 4091. The tex and ps files for this note are available in the CVS package `muon_note`.

1 Introduction

Muons in D0 can be identified through three independent detector subsystems. The 3 layer muon detector system with its toroid magnet covers more than 90% of the angular acceptance up to a pseudo-rapidity $|\eta| = 2$ provides unambigious muon identification. The DØ muon reconstruction makes 'local' muon segments in the three layers, and can combine these into 'local' muon tracks with a momentum measurement A muon identified on the basis of the information provided by the muon detector is called a "local muon".

The central tracking system (consisting of the Silicon Microstrip Tracker – SMT – and the Central Fiber Tracker – CFT) provides accurate momentum resolution and is highly efficient at finding tracks in the whole angular acceptance of the muon detector. A local muon that is successfully matched with a central track is called a "central track-matched muon".

A third independent muon confirmation can be obtained by looking for a MIP signature in the calorimeter. The capability to identify muons using the calorimeter is called "Muon Tracking in the Calorimeter" or "MTC" and is still in development. The current MTC algorithm has a typical efficiency of $\approx 50\%$, far less efficient than the other muon signatures.

Reconstructed muons are stored in the ThumbnailChunk as a list of MuonParticle objects, which are classified using two parameters: muon *type* (see section 2) and muon *quality* (see section 3). Typically, the quality (rather than type) definitions are used when selecting muons for analysis. The access methods of MuonParticle objects are listed in tables 3, 4, 5 and 8.

1.1 Changes for p17 Muon Reconstruction

The muon reconstruction in p17 does not have any significant algorithm changes compared to p14. however, there have been a number of updates:

- When combining segments in local tracking, the number if hits as well as χ^2 is now taken into account.
- Improved matching of central tracks to BC segments.
- PDT pad information is used to improve ϕ resolution in the central A-layer.
- Muon certification variable now filled by d0reco (e.g. isLoose, isCosmic etc).
- In the case of track matched muons, the default muon kinematics now come directly from the central track rather than a global fit (the central track was found to have better resolution than the global fit).
- Expanded error words.
- B and C layer scintillator times now available separately.
- Some unused variables removed from the TMB.

- The p17 thumbnail (or TMB++) also stores the muon hit chunks - the PDTHitChunk, MDTHitChunk and MSCHitChunk, as well as the central tracker hit chunks and calorimeter cells. This makes it possible to re-run the muon reconstruction from the TMB++.

In addition there have been a number of minor bug fixes and updates.

2 Muon Types

Muons types are classified according to the information available in the muon system, given by the parameter *nseg*. A positive value of *nseg* indicates that the muon reconstructed in the muon system ("local muon") was matched to a track in the central tracking system. A negative value of *nseg* tells that the local muon could not be matched to a central track. The absolute value $|nseg| = 0$, 1, 2, or 3 indicate the type of local muon segments used for this muon, if any. The different muon types with their respective values of *nseg* are listed in table 1.

In all cases, the same algorithm is used in matching central tracks to muon segments [3], which involves extrapolating the central tracks out to the muon system, then matching. In the case of a local muon with a converged fit, the matching is done in 4 dimensions (two positions, one angle and q/pT), for muons without converged fits, or individual A or BC segments, the matching is done in 3 dimensions (q/pT is not used). In the case where a central track could be matched then the default kinematic parameters of the muon (pT, η, ϕ etc.) are those of the central track. Additionally, in the case of a local muon with a converged fit, the muon and central track parameters are combined in a 'global fit', and the global fit parameters are also available.

If no central track could be matched then the 4-vector and η, ϕ and $\tan(\lambda)$ are given at the A-layer. The norm of the 4-vector is corrected for the most probable energy loss in the calorimeter using Run I parametrization. Particularities of the various muon types are detailed in the next subsections.

2.1 A+BC-segments with central track match (nseg=3)

A MuonParticle with nseg=3 consists of an A- and a BC-segment (a local muon track) matched to a central track. The 4-vector of the muon, its charge, η, ϕ, $\tan(\lambda)$ and z at the point of closest approach (zAtPca) come from the central track. Information from a combined fit of the muon+track is also available.

2.2 BC-segments with central track match (nseg=2)

A MuonParticle with nseg=2 consists of a BC-segment matched to a central track. The 4-vector of the muon, its charge, η, ϕ, $\tan(\lambda)$ and z at the point of closest approach (zAtPca) come from the central track. Information from a combined fit of the muon+track is also available.

2.3 A-segments with central track match (nseg=1)

A MuonParticle with nseg=1 consists of an A-segment matched to a central track. The 4-vector of the muon, its charge, η, ϕ, $\tan(\lambda)$ and z at the point of closest approach (zAtPca) come from the central track. Information from a combined fit of the muon+track is also available.

2.4 Muon hits or MTC matched to central track (nseg=0)

A MuonParticle with nseg=0 does not have any muon segment. It is either a central track matched to a muon *hit* or to a calorimeter muon (MTC). Here the 4-vector of the muon, its charge, η, ϕ, $\tan(\lambda)$ and z at the point of closest approach (zAtPca) are directly coming from the central track.

2.5 A-segments only (nseg=-1)

This type of MuonParticle consists of an A-segment only, not matched to a central track. In this case the momentum measured by the muon system (also called *local momentum*, given by *qptloc*()) is set to 0 and the $pT()$ is set to 100000. The η, ϕ and $\tan(\lambda)$ give the position of the A-segment. Here the 4-vector should not be used because no momentum measurement is provided [1].

2.6 BC-segments only (nseg=-2)

A MuonParticle with nseg=-2 consists of a BC-segment only, not matched to a central track. The transverse momentum and the 4-vector of the muon are estimated from the direction of the BC-segment with respect to the center of the detector.

2.7 A+BC-segments only (nseg=-3)

For a MuonParticle with nseg=-3 a first estimate of the transverse momentum is made from the curvature between A- and BC-segments. A fit of the A- and BC-segments into a local muon track is made. If the fit is successful the momentum of the fitted local muon track becomes the momentum of the muon. Otherwise the initial momentum estimate is kept.

[1] It is still computed though, by combining the default value $pT()$=100000 with η and ϕ of the A-segment.

nseg	Muon Type	Central Matching Algorithm	MTC Matching
3	Central track + local muon track (A + BC)	Central track to muon	$\Delta\eta$, $\Delta\phi$ between MTC and central track extrapolated to calo
2	Central track + BC-segment	as above	as above
1	Central track + A-segment	as above	as above
0	Central track + muon hit or Central track + MTC	as above	as above
-1	A-segment only	no match	$\Delta\eta$, $\Delta\phi$ between MTC and A-layer segment
-2	BC-segment only	no match	$\Delta\eta$, $\Delta\phi$ between MTC and BC-layer segment
-3	Local muon track (A + BC)	no match	$\Delta\eta$, $\Delta\phi$ between MTC and local muon local muon at A-layer if fit converged or else A-segment position.

Table 1: *Muon Types in the p17 Thumbnail.*

3 Muon Quality

The second parameter used to classify muons is the *quality*, and the quality definition is usually used when selecting muons for analysis. The muon quality can be "Loose", "Medium" or "Tight", and these definitions have not changed between p14 and p17. The Tight definition has actually remained unchanged since p10. The Medium and Loose efficiencies were optimized for release p14, by loosening the requirements on the local muon in regions with reduced acceptance and by instead requiring in these regions a confirmation from the central tracking system. However, in the case of non-isolated muons, there are indications that medium and loose muons suffer from higher background / fake rates, and in this case it may be preferable to require medium nseg=3 muons. The definitions for Tight, Medium and Loose are given below, and are implemented in the isLoose(), isMedium() and isTight() flags for each muon particle.

- **Tight muons**
  This definition has not changed since p10. Only $|nseg| = 3$ muons can be Tight. A muon is Tight if it has:

  - at least two A layer wire hits
  - at least one A layer scintillator hit
  - at least three BC layer wire hits
  - at least one BC scintillator hit
  - a converged local fit ($\chi^2_{\mathrm{loc}} > 0$)

- **$|nseg|$=3 Medium/Loose muons**
  When an $|nseg|$=3 muon candidate fails the Tight criteria it might still be Medium or Loose. An $|nseg| = 3$ muon is Medium if it has:

  - at least two A layer wire hits
  - at least one A layer scintillator hit
  - at least two BC layer wire hits
  - at least one BC scintillator hit (except for central muons with less than four BC wire hits).

  An $|nseg| = 3$ Loose muon is defined as a Medium muon but allowing one of the above tests to fail, with the A wire and scintillator requirement treated as one test and requiring always at least one scintillator.

- **$nseg$=+2 Loose/Medium muons**
  Muons with $|nseg| < 3$ can only be Loose or Medium if they are matched to a central track. $nseg$=2 muons are muons with a BC segment matched with a central track. Loose requires:

  - at least one BC layer scintillator hit
  - at least two BC layer wire hits

  An $nseg$=2 muon is defined as Medium if it fulfills the above requirements and if it is located in the bottom part of the detector (octant 5 and 6 with $|\eta^{detector}| < 1.6$).

- **$nseg$=+1 Loose/Medium muons**
  Muons with $nseg$=1 are muons with an A segment matched with a central track. An $nseg$=1 muon is Loose if it has:

  - at least one scintillator hit
  - at least two A layer wire hits.

An $nseg$=1 muon is defined as Medium if it fulfills the above requirements and if it is located in the bottom part of the detector (octant 5 and 6 with $|\eta^{detector}|$ <1.6). Low momentum $nseg$=1 muons are also defined as Medium. A $nseg$=1 muon is qualified as low momentum muon if its probability to reach the BC layer is less than 0.7 (this can be adjusted by RCP parameter in `muonid/rcp/MuonParticleReco.rcp`). The probability maps as a function of the muon momentum and $|\eta|$ are also set by RCP. Figure 1 shows the probability curves (markers) computed with Geant for generated muons with 3<p<4 GeV, 4<p<5 GeV and 5<p<6 GeV.

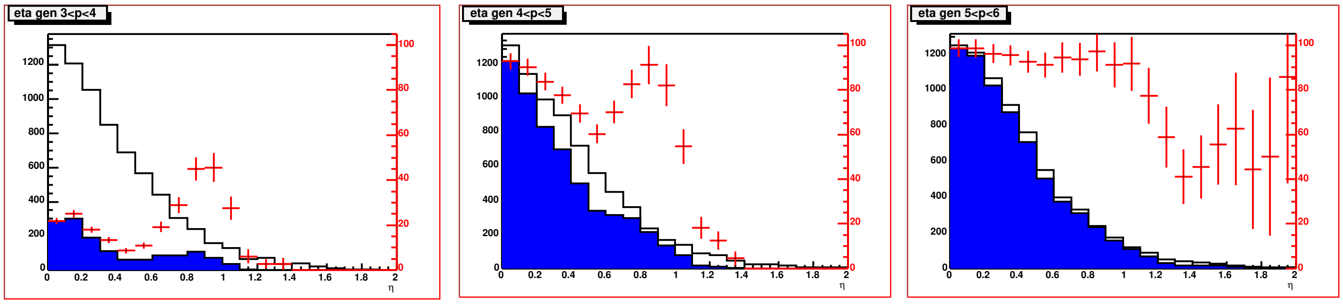

Figure 1: *The fraction of muons reaching the BC layer as a function of* η *(markers), determined from GEANT simulation, for different bins of generated momentum: 3<p<4 (left), 4<p<5 (middle) and 5<p<6 GeV (right). The open (shaded) histograms show the* η *distribution of the generated muons before (after) reaching the BC layer.*

4 Cosmic Cuts

To identify muons from cosmic rays, two selections are implemented in reco. First, if any scintillator hits are out of time, the isCosmic flag is set to 1. The actual cut used is $|time| >$ 10 ns, and this can be changed in MuonParticleReco.rcp in the muonid package. Secondly, if a muon has a matched track and that track has a dca > 0.16 cm and out of time scintillator hits, the isCosmicT() flag is set to 1. Again, the dca cut value can be set in the rcp file.

5 Muon Isolation Variables

The most commonly used isolation variables are EtHalo() and etTrkCone5(). EtHalo() is the sum of calorimeter transverse energy in a 0.4 cone around the muon, minus the transverse energy in a 0.1 cone around the muon. Energy in the coarse hadronic layers is not included in this calculation. etTrkCone5() is a sum of pT of all central tracks in a 0.5 cone around the muon, excluding the muon track itself. Only tracks which originate within 2 cm in z of the muon are used in the sum. nTrk5() gives the number of tracks used.

The variables EInConeX give the energy deposited in all calorimeter cells (except coarse hadronic) that are within $\Delta R < X$ of the muon. These variables generally do not perform as well as EtHalo().

For all isolation variables, the η, ϕ of the matched central track is use. If not track is matched, the η, ϕ of the muon at the A-layer is used, and for $nseg()$=-2 the η, ϕ direction of the BC-segment is used.

6 pT Correction for CFT-only Central Tracks

The presence of SMT hits on a central track significantly improves the momentum resolution of that track. However, typically around 20-30% of central tracks do not have SMT hits, due mostly to the limited SMT coverage, and partly due to detector inefficiency.

In order to improve the momentum resolution for tracks without SMT hits (CFT-only tracks), a common trick is to adjust the track curvature (q/pT) so the track goes through the primary vertex in the x-y plane. This change to q/pT is derived in Appendix A and takes the form:

$$\frac{q}{p_T}' = \frac{q}{p_T} - dca \times \frac{\sigma_{r,\frac{q}{p_T}}}{\sigma_{r,r}}, \tag{1}$$

where σ is an elements in the central track error matrix and dca is the distance of closest approach to the primary vertex. This correction is implemented in the muon reconstruction, and the function pTcorr() returns the corrected value for pT. In the case of tracks with SMT hits, this correction is not applied, and pTcorr() simply returns the original pT of the central track.

In low occupancy events, such as $W \rightarrow \mu$ or $Z \rightarrow \mu\mu$, the primary vertex position is biased, and better results can be obtained using the beam spot position. This is produced by the AATrack algorithm, and is available in AATrack/dat/beamspot-2.09. The central track parameter r gives the track dca to 0,0 in x-y. This can be converted to the dca to the beam position by

$$dca = r - x_{beam} \times cos\phi + y_{beam} \times sin\phi, \tag{2}$$

where x_{beam} and y_{beam} are the beam spot coordinates. This is not implemented in default muon reconstruction.

7 Accessing Muon Hits

For each muon particle, some information is stored on the associated muon detector hits. This can be accessed by the IndexVec() function, which returns a vector of integers. These can be converted to muon hit indicies by the `Int_to_index` function defined in `muo_evt/MuonParticle.hpp`. Additionally, one tome is stored for each hit, accessible as a vector of floats with the TimeVec() function. This is the drift time in the case of PDT or MDT hits, and the hit time in the case of MSC hits. The index and time can be used to uniquely identify the associated hits in the muon hit chunks.

Alternatively, the function getMuonHits(const muonid::MuonParticle mu) defined in muonid/MuoCandidate.hpp returns a vector of hits for a given muon, with information such as the hit type, region, octant, position available. The hit struct is defined in muonid/MuoCandidate.hpp.

8 Muon data quality words

The muon front ends have been programmed in order to write several error flags into the level-3 muon module headers of the raw data. The Event Status Register 2 is used to store these error flags. For the time being, error flags for turn or crossing number mismatches, SRQ and RVS errors are implemented. For more information, see [2]

These error flags are read by the reconstruction software at the unpacking level, and a summary information is built. There are 12 muon crates (x30 to x3b), each with a different number of active modules. For each module, one bit is used to indicate the presence of a turn or crossing number mismatch (a sync error). At the time of writing, these errors are rare and have been made fatal - the readout should stop if such an error occurs, and such errors should not show up in the data. For each crate, one bit is also used to flag any SRQ or RVS errors, which are also fatal errors.

In the thumbnail the muon data quality words are stored in the TMBTriggerChunk inside the *Global* information. Six 32 bit words are used, and their content is summarised in table 2. Quality words are access functions are `thumbnail::Global::get_muon_qual1()` and `thumbnail::Global::get_muon_qual2()` etc, defined in the `config_base` package.

Additionally, in the MuonQualityInfo.cpp in the `muo_evt` package, the following functions are defined: isMuonEventOk which returns 1, or 0 if any errors are present; NXingMismatch which takes a crate number as a an argument, and returns the number of crossing or turn errors in that crate; RVSerror returns true or false if there are RVS errors in a given crate; SRQerror returns true or false if there are SRQ errors in a given crate.

9 Warnings and known bugs

9.1 Overflows and underflows

All variables that are stored in the thumbnail are allocated a number of bits and a range. After packing and unpacking of the thumbnail any variable with a value beyond the allocated range will instead take the maximum or minimum value of the range. Therefore when working on thumbnails it is important to know what the range of each variable is and to check that the value of a variable is not at the minimum or maximum of its range before using it in an analysis.

9.2 Impact parameter significance

The impact parameter significance (2nd parameter returned by *void* $impPar(ip, iperr)$) is packed in the range -10:10 which is too small.

Muon Quality Words	
Quality Word	**Bit Assignment**
1	0 = RVS error, crate 0x30 1 = SRQ error, crate 0x30 2-14 = Sync errors, 12 modules in crate 0x30 15 = RVS error, crate 0x32 16 = SRQ error, crate 0x32 17-22 = Sync errors, 6 modules in crate 0x32 23 = RVS error, crate 0x37 24 = SRQ error, crate 0x37 25-27 = Sync errors, 3 modules in crate 0x32
2	0 = RVS error, crate 0x31 1 = SRQ error, crate 0x31 2-14 = Sync errors, 12 modules in crate 0x31 15 = RVS error, crate 0x33 16 = SRQ error, crate 0x33 17-22 = Sync errors, 6 modules in crate 0x33 23 = RVS error, crate 0x3b 24 = SRQ error, crate 0x3b 25-27 = Sync errors, 3 modules in crate 0x3b
3	0 = RVS error, crate 0x34 1 = SRQ error, crate 0x34 2-15 = Sync errors, 13 modules in crate 0x34 16 = RVS error, crate 0x36 17 = SRQ error, crate 0x36 18-28 = Sync errors, 11 modules in crate 0x36
4	0 = RVS error, crate 0x35 1 = SRQ error, crate 0x35 2-24 = Sync errors, 23 modules in crate 0x35
5	0 = RVS error, crate 0x38 1 = SRQ error, crate 0x38 2-15 = Sync errors, 13 modules in crate 0x38 16 = RVS error, crate 0x3a 17 = SRQ error, crate 0x3a 18-28 = Sync errors, 11 modules in crate 0x3a
6	0 = RVS error, crate 0x39 1 = SRQ error, crate 0x39 2-24 = Sync errors, 23 modules in crate 0x39

Table 2: *Muon quality word bit assignment in p17. A sync error can be either a turn or crossing error mismatch.*

References

[1] *MuonID version 2.0*, MuonID Group, http://www-d0.fnal.gov/phys_id/muon_id/d0_private/docs.html

[2] *Data quality bits for the muon system*, Dennis Shpakov, presentation at the Muon system operation and software meeting, October 8, 2002. Available at: http://www-d0.fnal.gov/computing/algorithms/muon/meeting-100802/

[3] *Update of Muon Central Matching for p16*, Boris Tuchming, presentation at the Muon ID/Algorithms Meeting, 21 October 2003. Available on the DØAgenda Server.

MuonParticle Accessors			
Method Name	**Description**	**Default**	**Range**
float pT()	Transverse momentum (see §2)	100000	0.25:∞
float px()	Momentum x component (see §2)	see §2.5	NP
float py()	Momentum y component	“	NP
float pz()	Momentum z component	“	NP
float p()	Total momentum	“	NP
float E()	Energy	“	NP
void p4vec(float p4v[4])	Returns 4-vector $\vec{P}, E$ (see §2)	“	NP
float eta()	η of central track or at A-layer (see §2)	always defined	NP
float theta()	θ of central track or at A-layer (see §2)	always defined	NP
float tanlam()	tan(λ) of central track or at A-layer (see §2)	always defined	-60:60
float phi()	ϕ of central track or at A-layer (see §2)	always defined	0:6.4
float charge()	Charge	0	-1:1
LinkIndex vtxindex()	Index of associated vertex	0	0:255
LinkIndex chpLink()	Index of associated charged particle	0	0:255
float zAtPca()	z at Pca	120	-120:120
void impPar(float &iP,	Impact parameter and its error	10	-10:10
float &iPerr)	wrt the center of DØ	10	0:10
void errMatrix(MatrixD & m)	Error matrix (see table 6)		
void p4vecGlobal(float p4v[4])	Returns 4-vector $\vec{P}, E$ (see §2)	“	NP
float pTGlobal()	pT from global fit (see §2)	100000	0.25:∞
float etaGlobal()	η from global fit (see §2)	100000	0.25:∞
float phiGlobal()	ϕ from global fit (see §2)	100000	0.25:∞
int typeID()	+13 for μ^- and -13 for μ^+	-	-13:13
MuonQualityInfo * qualInfo()	Muon quality information	-	-
vector<int> IndexVec()	Vector of indicies of associated hits (see §7)	-	-
vector<float> TimeVec()	Vector of times of associated hits (see §7)	-	-

Table 3: *MuonParticle access methods in p17. The default value gives the value returned by the method when no valid result is available. NP means that this variable is not packed in the thumbnail but is computed from other variables packed in the thumbnail. The MuonParticle 4-vector is calculated either from the information at A-layer if there is no matched central track or comes directly from the central track. The combined central track and local muon information is stored as the 'Global' parameters (see §2). Energies are in GeV and momenta in GeV/c. Functions in this table are defined in muo_evt/MuonParticle.hpp.*

MuonQualityInfo Accessors - Table I			
Method Name	**Description**	**Default**	**Range**
Local muon information			
float chisqloc()	χ^2 of local muon fit (-1 if failed fit)	-1	-1:2.68 10^8
float qptloc()	q/p_T for local p_T	6	-6:6
int nseg()	=0 (no segment - i.e. MTC) ±1 (A-segment) ±2 (BC-segment) ±3 (A+BC segment) nseg()>0 if central track match nseg()<0 if no central track match	0	-3:3
int nhit()	nwhitA+10.nwhitB+100.nwhitC+ 1000.nshitA+10000.nshitB+100000.nshitC	-1	-1:262144
int ndeck()	nwdeckA+10.nwdeckB+100.nwdeckC+ 1000.nsdeckA+10000.nsdeckB+100000.nsdeckC	-1	-1:262144
int region()	0 = central muons, 1 = forward $z < 0$, 2 = forward $z > 0$	-1	-1:2
int octant()	Octant number (0 to 7)	-1	-1:7
float whitsA(), B(), C()	# A, B or C-layer Wire Hits	-1	0-9
float whitsBC()	# B+C-layer Wire Hits	-1	0-9
float shitsA(), B(), C()	# A, B or C-layer Scintillator Hits	-1	0-9
float shitsBC()	# B+C-layer Scintillator Hits	-1	0-9
float sctimeA(), B(), C()	Scintillator time in A, B or C-layer	999	-40:40
float expWhitsA(), BC()	Expected wire hits	-1	not filled
float expShitsA(), BC()	Expected scintillator hits	-1	not filled
int categoryloc()	-2 for BC segment only -1 for A-stub 0 for A+BC segment, no fit 1 for A+BC segment with converged fit	-1	-2:1
float xA(), yA(), zA()	x,y,z of the middle point of A-segment	999	-400:400
Note that if there is a successful local fit then xA, yA, zA are the position of the fit at A-layer			
float pxA(), pyA(), pzA()	Momentum from fit at A-layer	999	-1000:1000
float etaA()	η from fit at A-layer	999	NP
float thetaA()	θ from fit at A-layer	999	NP
float phiA()	ϕ from fit at A-layer	999	NP
int qualityloc()	See table 7	-1	-1:5
int statusloc()	Status of the local muon fit (obsolete)	-1	obsolete
float bdl()	Path integral of magnetic field	-1	not filled

Table 4: *MuonQualityInfo access methods in p17 - table I. The default value gives the value returned by the method when no valid result is available. Scintillator times are expressed in ns. The variables nwdeckA, nwdeckBC are the number of wire sublayers (or decks) fired in the A- resp. BC-layer.*

MuonQualityInfo Accessors - Table II			
Muon Quality			
int isLoose()	Passed the Loose requirements (see §3)	-1	0-1
int isMedium()	Passed the Medium requirements (see §3)	-1	0-1
int isTight()	Passed the Tight requirements (see §3)	-1	0-1
int isCosmic()	Fails the cosmic cuts(see §4)	-1	0-1
int isCosmicT()	Fails the tight cosmic cuts (see §4)	-1	0-1
Miscellaneous			
int isOK()	Set to 0 if any readout errors in this event	-1	not filled
int muoTrackIndex()	Index of local muon in muon::TrackChunk	255	0:255
bool isTightMuoTrack()	Is it a tight muon according to p10 & p11 ID criteria?	0	0:1
int segIndex()	Index of segment in the segment chunk	-1	not filled

Table 5: *MuonQualityInfo access methods in p17 - table II.*

	$impPar$	$zAtPca$	ϕ	$\tan(\lambda)$	q/pT
$impPar$	6	7	8	9	10
$zAtPca$		11	12	13	14
ϕ			0	1	2
$\tan(\lambda)$				3	4
q/pt					5

Table 6: *The elements of the error matrix returned by the method void MuonParticle::errMatrix()*

	qualityloc()			
categoryloc()	1	2	3	4
-2 (BC segment only)	nWhit≤2 nShit=0	nWhit>2 nShit=0	nWhit>2 nShit≥1	
-1 (A segment only)	nWhit≤1 nShit=0	nWhit≥2 nShit=0	nWhit≥2 nShit≥1	
0 (A+BC segment, no fit)	nWhitA=0 or nWhitBC=0	nWhitA≥1 nWhitBC≥1	nWhitA≥2 nShitBC≥3	
1 (A+BC segment, converged fit)	nWhitA=0 or nWhitBC=0	nWhitA≥1 nWhitBC≥1	nWhitA≥2 nWhitBC≥3	nWhitA≥2 nWhitBC≥3 nShitA≥1 nShitBC≥1 $\chi^2 \geq 0$

Table 7: *The qualityloc() method. qualityloc() returns values between 1 and 4. The meaning of qualityloc() depends on the category() of the muon (A+BC w or w/o converged fit, only A or only BC segment). $nWhit$ (nShit) is the total number of wire (scintillator hits). $nWhitA$ ($nWhitBC$) is the number of wire hits in the A (BC) layer. $nShitA$ ($nShitBC$) is the number of scintillator hits in the A (BC) layer. χ^2 is from the local muon track fit.*

MuonQualityInfo Accessors - Table III			
Method Name	**Description**	**Default**	**Range**
Central track match information			
int ncentralmatch()	Number of matched central tracks	-1	-1:128
int centralrank()	Rank of the central track match	-1	-1:128
int chpIndex()	Index of matching particle in charged particle chunk	255	0:255
float chisq()	χ^2 of the central track match	-1	-1:2.68 10^8
float dof()	# d.o.f. in the central track match	-1	-1:16
float deltaPhi()	$\Delta\phi$ between A-layer segment and matching charged particle	9	-10:10
float deltaEta()	$\Delta\eta$ between A-layer segment and matching charged particle	9	-10:10
float deltaDrift()	Distance along z in cm between A-layer segment and matching charged particle extrapolated linearly to A-layer	999	-1000:1000
float dca()	*dca* of the matched central track	-1	-1:2.68 10^8
float etaCentral()	η of the matched central track	-1	-1:2.68 10^8
float phiCentral()	ϕ of the matched central track	-1	-1:2.68 10^8
Isolation Variables (see §5)			
float etHalo()	Calorimeter halo E_T	-1	-1:100
float etTrkCone5()	Tracker halo pT	-1	-1:500
int nTrk5()	Number of tracks in halo	-1	-1:100
float drJet5()	ΔR to nearest jet	-1	not filled
float EInCone1()	Calorimeter energy in a ΔR=0.1 cone around muon	-10	-10:100
float EInCone15()	Same as above with a 0.15 cone	-10	-10:100
float EInCone2()	Same as above with a 0.2 cone	-10	-10:100
float EInCone4()	Same as above with a 0.4 cone	-10	-10:100
float EInCone6()	Same as above with a 0.6 cone	-10	-10:100
float eloss()	Expected energy lost in the calorimeter	-10	-10:100
MTC variables			
int nmtc()	number of calorimeter muons	-1	-1:1
int CalNLayer()	Number of calorimeter layers	0	0:7
float CalEsig()	Energy signature	-1	-1:1
float CalEta()	η of calorimeter muon	99	-10:10
float CalPhi()	ϕ of calorimeter muon	99	-10:10
float roadEM()	EM energy in road method	99	not filled
float roadFine()	Fine Hadronic energy in road method	99	not filled
float roadCourse()	Course Hadronic energy in road method	99	not filled
float roadOutFloor()	Floor in road method	99	not filled

Table 8: *MuonQualityInfo access methods in p17 - table III. The default value gives the value returned by the method when no valid result is available.*

A Derivation of the CFT-only Track Correction

The idea is to vary the track parameters r and q/pT within their uncertainties, then optimise the χ^2 to get the best value of q/pT for a given r, where r is the distance of closest approach of the fitted track to 0,0 in the x-y plane.

Writing the χ^2 as:

$$\chi^2 = (r - r_f, \frac{q}{p_T} - \frac{q}{p_{T\,f}})V^{-1}_{r,\frac{q}{p_T}} \begin{pmatrix} r - r_f \\ \frac{q}{p_T} - \frac{q}{p_{T\,f}} \end{pmatrix} \tag{3}$$

where r_f and $\frac{q}{p_{T\,f}}$ are the results of the original track fit. The error matrix and its inverse are given by:

$$V_{r,\frac{q}{p_T}} = \begin{pmatrix} \sigma_{r,r} & \sigma_{r,\frac{q}{p_T}} \\ \sigma_{r,\frac{q}{p_T}} & \sigma_{\frac{q}{p_T},\frac{q}{p_T}} \end{pmatrix} \tag{4}$$

$$V^{-1}_{r,\frac{q}{p_T}} = \frac{1}{\sigma_{r,r}\sigma_{\frac{q}{p_T},\frac{q}{p_T}} - \sigma^2_{r,\frac{q}{p_T}}} \begin{pmatrix} \sigma_{\frac{q}{p_T},\frac{q}{p_T}} & -\sigma_{r,\frac{q}{p_T}} \\ -\sigma_{r,\frac{q}{p_T}} & \sigma_{r,r} \end{pmatrix} = \begin{pmatrix} a_{1,1} & a_{1,2} \\ a_{2,1} & a_{2,2} \end{pmatrix} \tag{5}$$

where $a_{x,y}$ is simply used for shorthand.

The χ^2 can thus be written as:

$$\chi^2 = a_{1,1}(r - r_f)^2 + a_{2,2}(\frac{q}{p_T} - \frac{q}{p_{T\,f}})^2 + 2a_{1,2}(r - r_f)(\frac{q}{p_T} - \frac{q}{p_{T\,f}}) \tag{6}$$

To find the value of q/pT which optimises the χ^2, we set $\frac{d\chi^2}{d\frac{q}{p_T}} = 0$. This gives:

$$\frac{q}{p_T} = \frac{q}{p_{T\,f}} - \frac{a_{1,2}}{a_{2,2}}(r - r_f) \tag{7}$$

Substituting in the values of a from equation 5 gives:

$$\frac{q}{p_T} = \frac{q}{p_{T\,f}} + \frac{\sigma_{r,\frac{q}{p_T}}}{\sigma_{r,r}}(r - r_f) \tag{8}$$

Finally, we choose the value of r wanted for the corrected track. Typically, this is chosen to be the position of the primary vertex, or of the beam spot. The value of $(r - r_f)$ is then the distance of closest approach of the original track to the beam position or primary vertex, denoted dca. The final correction is thus:

$$\frac{q}{p_T} = \frac{q}{p_{T\,f}} - dca \times \frac{\sigma_{r,\frac{q}{p_T}}}{\sigma_{r,r}} \tag{9}$$