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Muon Data Formats to L2 & L3

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Differences from V 1.0:

1. All new L2 formats (1 16-bit word of complete address + 1 16-bit word of data for each hit).
2. Major revision of MDT L3 format.
3. MCEN formats added.

Differences from V 2.0:

1. Superfluous word counts removed..
2. MCEN formats updated per JMB/EM.
3. “DSP” removed from document title.

Differences from V 2.1:

1. VBD word count and padding trailer added to L3 header.
2. Psi offsets added to alignment constants.
3. Second crossing number word added to keep track of all 3 version of the crossing number.
4. Some bits defined in error/status register (calib, 1/n).
5. Pad word counts per wire included in PDT L3 format.
6. Explictly state which word counts include themselves.

Difference from V 2.2:

1. Extra crossing numbers removed from L2 and L3 headers (back to V2.1).
2. Fixed small errors:
    - Spurious “Data Word Count” removed from MCEN L2 format.
    - MTD tube address tables fixed.
    - CMSC module numbers corrected.
    - Several typos fixed.
3. MCEN hit maps changed to 16-bits in L2 format.

Difference from V 2.3:

1. The version number is 3.0, preceeded by V 2.3.
2. The header length of 8 words has been corrected to 6 words in both the L2 and L3 Header Block Words description.
3. A brief description of the 3 subdetectors namely, PDTs, Scintillators and MDTs is given after the L2 Format (General) heading.
4. In the PDT L3 Data Format, the pad hit count has been reduced to 2 bits in the Hit Data Word Count.
5. In the L2 Scintillator Data Format, Time has been increased to 15 bits and spare bit removed.
6. In the L3 Scintillator Data Format, the first word of Hit Channel Count has been split into 2 words of Hit Channel Count and SFE Hit #, the latter increased to 4 bits.
7. Some additional comments have been added at few places to make things more clear and a few other numbers corrected.
8. Appropriate references are mentioned for TZeros etc.

Differences between V3.1 and V3.0:

1. Module numbers of FMSC crates are updated.

2. A description of the L3 muon crate header is added.
3. PDT orientations are described.
4. The exceptional counters in CMSC (bottom-C, side-B, etc.) are itemized with their corresponding SFEs.

Differences between V3.2 and V3.1:

1. MCEN L3 format corrected (to look more like L2).
2. PMT numbers updated for CMSC-A and FMSC to agree with cabling notes.
3. Local phi index added to time word in L2 scint format.
4. A clear description of the Module ID is given.

Differences between V3.3 and V3.2:

1. L3 SFE hit word changed so that the number of SFE's hit is in the lowest four bits.
2. L3 SFE address word changed to include a hit count for each SFE
3. Time and local phi word changed for L3 scint to give finer time resolution
4. Crate header word count moved to first word, and crate word count moved to second word
5. Wire length constant added to hit count word for L3 PDT data
6. Orientation information corrected for PDT's 115,116,135,136

Difference between V3.4 and V3.3;

1. maximum number of MDC in a crate corrected from 14 to 12
2. fixed ambiguous description of SFE count in scint L3 header

Introduction

This note describes the data formats produced in the front-end Digital Signal Processors (DSPs) of the muon system. The DSPs send data to both L2 and L3, with specific formats for each.

For a general description of the data processing in the DSP (ADSP-21csp01) for data readout, buffering and formatting, refer to the D0 Note 3655.

For details on the hardware or electronics of the detectors, refer to the D0 Note 3299.

For details on the PDT data processing in the DSP, refer to the D0 Note 3659.

For a spec and brief description on the buffering scheme of the DSP, refer to the D0 Note 3674.

L2 Format (General)

The level 2 input DSPs build up 32-bit words, each of which must fully specify the address and relevant data for a hit. The readout DSPs feed these to Level-2 as two 16-bit words, the first of which gives the complete address of the object hit (PDT cell, scint counter, or MDT 8-cell tube), and the second word of which contains and other relevant information (drift distance, time of hit...). Since the addresses in the first word are complete, they contain some information which is redundant with the module ID in the header. The module ID is kept in the header for diagnostic purposes and to make it uniform with the Level 3 headers.

L2 Muon Module Header Format

Common to L2 data from all muon subsystems.

16-bit Word Count (FE)
Module ID
Crossing #
Turn #
Event Status Register I
Event Status Register II

Front End Word Count:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FE word count															

FE word count: Inclusive number of 16-bit words in the data block.
The header length (6 words) is included in the count, including the word count word itself.

Module ID:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
						Layer		Barrel				Octant			

The module ID is a hexadecimal representation , where the above three fields take the following range of values.

1. Layer (index of r) = 0-2 (2 bits)

    A-layer = 0
    A&B-layer (combined) = 0
    B-layer = 1
    C-layer = 2

2. Barrel (index of eta) = 0-9 (4 bits)
    PDT = 0-4 (north to south)
    CMSC = 5
    MDT north, MCCM north = 6
    FMSC north = 7
    MDT south, MCCM south = 8
    FMSC south = 9

3. Octant (index of phi) = 0-9 (4 bits)

    PDT = 0-7
    MDT = 0,2,4,6
    CMSC = 0,1,2,3,5,6 (0 includes oct 7, 3 includes oct 4)
    FMSC-A&B = 0,2,4,6
    FMSC-C east = 8
    FMSC-C west = 9
    MCCM = 8

Crossing # :

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Spare								Event crossing # (L1)							

An error bit is set in the Event Status Register I, if the Local crossing # from the counter on the Control Board (PDT)/VME crate (MDT, Scintillators), differs from the L1 event crossing number from the TFW.

Turn #:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Turn #															

Local turn # from the Control Board/VME crate, as the case may be.

Event Status Register I:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
alignment const. set ID						error / status bits									

Bit 0 = calibration data
Bit 1 = 1/n data (MCENs)
Bit 2 = L2 buffers full (0 normal, 1 when all L2 output buffers full)
Bit 3 = crossing number mismatch at L1 (0 normal, 1 mismatch)
Bit 4 = L3 buffers full (0 normal, 1 when all L3 buffers are full)); only filled in L3 version of the header
Bit 5 = crossing number mismatch at L2 (0 normal, 1 mismatch); only filled in L3 version of the header
Bits 6-9 are defined by each subsystem.
Bits 10-15 = Alignment const. set ID: 6 bits → up to 63 sets (~10 alignment sets in run 1).

Event Status Register II:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
error		DSP code version #			Calibration const. set ID										

Bits 0-10 = Calibration const. set ID: 11 bits → up to 2047 sets (~ 2/day for 3 years).
Bits 11-13 = DSP code version #: all for up to 8 versions
Bit 14: spare
Bit 15: data size exceeds input buffer size (1k for PDT's) => junk

L3 Muon Crate Header Format

This should not be confused with the generic L3 header that is appended by the VBD.
Note: this header (only) is listed in 32-bit words.

Crate Header word count
Crate ID/status
Number of modules read

Crate header word count: length of the muon crate header in 32-bit words, not including this count word (=2)

Crate ID/Status:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Crate ID																Error/Status															

Crate IDs will appear in a separate document once they are assigned.
The error/status bits will be defined later.

Number of modules read: 0-24

L3 Muon Module Header Format

Common to L3 data from all muon subsystems.

0
VBD Word Count (32-bit)
16-bit Word Count (FE)
Module ID
Crossing #
Turn #
Event Status Register I
Event Status Register II

The first VBD transfer word is zero, which represents the upper 16 bits of the 32-bit VBD word count. This is set to zero since the total number of words is never expected to be greater than 16 bits. But if it is, then the error bit is set in the header block and the upper 16-bits still set to zero.

VBD Word Count

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
VBD word count															

Total word count: Exclusive # of words 32-bit following this word. The length of the rest of the header (6 words) is included in the count, but not the VBD count words themselves. If the total number of 16-bit words is odd, then a 16-bit padding word ($aa55) is added at the end as a trailer.

16-bit Word Count: same as in L2 header. It includes itself, but not the VBD word count words nor the padding word (if present).

Module ID: same as in L2 header

Crossing #: same as in L2 header

Turn #: same as in L2 header

Event Status Registers I & II: same as in L2 header

L3 Muon Module Trailer Format

Common to L3 data from all muon subsystems.

Padding word = $aa55

This trailer word is present only if the 16-bit word count is odd. It is provided to pad out the last longword in the data block, since the VBD executes 32-bit transfers.

PDT (Proportional Drift Tubes) Formats

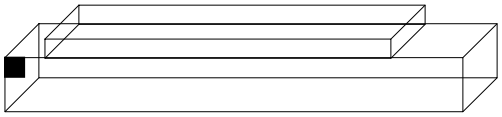
General PDT Hardware Description

The PDT chambers are made of 3-4 decks, with 24 wires per deck. The two adjacent wires in a deck are paired together with a delay jumper at the end, to distinguish from which wire the hit came from. These two wires make a pair.
There are two cathode pads ("inner" and "outer") for each wire. These are instrumented for every cell in the A-layer chambers, but only for 3/12 cells in the B- and C-layer chambers.

For the purpose of L2 formats, only pairs are picked up. If the data for one of the two wires of the pair is missing, the pair is still reported. Also, multiple hits on the same wire of the pair are ignored. However, if there are two hits on the two different wires of the pair, both are reported. (For details refer to D0 Note 3659). There are a total of 9,500 channels and 94 DSPs, for the PDT system.

The data from the Front_Ends is always pair ordered, but within a pair the order is not defined.
Each phi octant of each layer is divided among five PDTs in the z-direction, except for B-layer octants 5 and 6 (chambers 105,115,135,145 and 106,116,136,146) which are divided among four, and all A-layer octants, which are divided among three. All PDTs span one octant in phi, except PDT's 010,020,030 (which cover octants 7 and 0) and PDT's 013,023,033 (which cover octants 3 and 4).

The orientation of each PDT is defined by location of the readout electronics. Tube 0 is the one closest to the left-hand edge of the front end board, as one faces a chamber with the boards on top:

0 

There are four possible orientations, with the following relationships:

Orientation	Cell 0 r	Cell 0 phi	Cell 0 z	Representative PDT numbers (as used in Run I, 3-digit decimal no.)
0	Low	Low	Low	010,015,011,202,203,206,207,(115,135)
1	Low	High	High	013,016,012,200,201,204,205,(116,136)
2	High	Low	High	100,101,104 (106,146)
3	High	High	Low	102,103,116,107, (105,145)

The orientation of any given PDT is the same as one with the same layer and phi index in the table above, except for modules 105,106,145,146, 115, 116, 135, 136 which are given explicitly.

Note: All chambers remain in the same orientation as in Run 1 except 115, 135, 116, 136 which are rotated by 180 degrees about the x-axis.

The PDT TZero (T0) for a given wire is defined as the reported time for a relativistic particle emanating from the interaction point (IP) on a given crossing which hits the readout end of that wire. PDT drift time and signal propagation time along wires are not subtracted as part of the T0. They are measured for each hit and used to calculate axial and radial positions with respect to wires.
(For details on TZeros for all the 3 subsystems, refer to the D0 Note 3497).

PDT L2 Data Format

COMMON HEADER
Wire #
Drift dist & phi position
Wire #
Drift dist & phi position
Wire #
...

Wire # :

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Type =0	Layer =0-2		Octant =0-7			Eta Barrel =0-4			Pair number =0-11				Deck (plane)		Pair mem

Type: 0=drift tube, 1=scintillation counter
The local wire number in a chamber is given by bits 6-0. The local wire number increases with the readout order. The local wire numbers are show below for a 4-deck PDT (similar scheme for 3-deck PDT's, with increasing r layer removed):

Decimal:

0	1	8	9	16	17	24	25	32	33	40	41	48	49	56	57	64	65	72	73	80	81	88	89
2	3	10	11	18	19	26	27	34	35	42	43	50	51	58	59	66	67	74	75	82	83	90	91
4	5	12	13	20	21	28	29	36	37	44	45	52	53	60	61	68	69	76	77	84	85	92	93
6	7	14	15	22	23	30	31	38	39	46	47	54	55	62	63	70	71	78	79	86	87	94	95

Hex:

0	1	8	9	10	11	18	19	20	21	28	29	30	31	38	39	40	41	48	49	50	51	58	59
2	3	A	B	12	13	1A	1B	22	23	2A	2B	32	33	3A	3B	42	43	4A	4B	52	53	5A	5B
4	5	C	D	14	15	1C	1D	24	25	2C	2D	34	35	3C	3D	44	45	4C	4D	54	55	5C	5D
6	7	E	F	16	17	1E	1F	26	27	2E	2F	36	37	3E	3F	46	47	4E	4F	56	57	5E	5F

Drift distance and phi position:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Status bits			Local phi (2pi/160)					Drift distance (400 μm)							

Drift distance perpendicular to wire with respect to wire position; includes T0 subtraction.
The local phi divides each octant into 20 equal phi slices. This is comparable to the Delta-time resolution, and it is convenient for matching with the CFT and the A-phi systems, which divide octants into 10 slices.

Status: bit 13: 0 = single hit; 1 = multi-hit
bit 14: 1 = missing wire signal
bit 15: 1 = drift time/axial time error

PDT L3 Data Format

COMMON HEADER
Reference x/y Offsets
Reference z/θ Offset
Reference ϕ/ψ Offsets
Wire length/Hit Wire Count
Wire # / Status
Hit Data Word Count
Time 0
Time 1
...
Pad Signal A
Pad Signal B
Wire # / Status
...

Reference x/y Offsets:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Sign	y offset distance (100 μm)							sign	x offset distance (100 μm)						

Distance of reference point for this PDT from its nominal position (as defined by geometry constants).
7 bits + 1 sign bit → 0.1 mm resolution over up to +/- 12.7 mm.

Reference z/theta Offset:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Sign	z offset distance (100 μm)							sign	theta offset (10 μrad)						

Distance of reference point for this PDT from its nominal position (as defined by geometry constants).
7 bits + 1 sign bit → 0.1 mm resolution over up to +/- 12.7 mm.
Theta offset: angle of PDT theta reference with respect to its nominal angle (as defined by geometry constants).
7 bits + 1 sign bit → 0.01 mrad resolution over up to +/- 1.27 mrad.

Reference phi/psi Offsets:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Sign	phi offset (10 μrad)							sign	psi offset (10 μrad)						

Phi offset: angle of PDT phi reference with respect to its nominal angle (as defined by geometry constants).
7 bits + 1 sign bit → 0.01 mrad resolution over up to +/- 1.27 mrad.
Psi offset: angle of PDT psi reference with respect to its nominal angle (as defined by geometry constants).
7 bits + 1 sign bit → 0.01 mrad resolution over up to +/- 1.27 mrad.

Hit Wire Count:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Wire length constant (100 ps)									Hit wire count						

Number of wires with hits.
Max. # of wire channels = (4 FEB's)*(24 channels) = 96 → 7 bits.
Max wire length (L): ~562 cm.
Wire Length constant = L/v + J/2; where, v is the velocity with which the signal passes through the length of the wire [v = c/2= (30cm/ns)/2] and J is the jumper delay at the end of the wire.
Max. value of the Wire Length const = ~500,00 ps or 500 (100ps) → 9 bits.

The Hit Wire Count will always be an even number because both the wires of the pair will be reported. If there is no data (both time and pad data missing)for one of the two wires of the pair, the wire will still be reported (for sake of completion in terms of a pair) with the Hit Data Word Count (word next to Wire #) set to zero.

Wire # : Same as for L2.

Hit Data Word Count:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Spare						pad hit count		Spare					wire hit count		

Wire Hit Count = number of time data words following this word for this wire.
< 8 hits recorded per wire → 3 bits.
Pad Hit Count = number of pad data words following this word for this wire.
≤ 2 hits recorded per wire → 2 bits.

Time:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
spare		Sign	time (100 ps)												

T0-subtracted time.
1.2 ns bin width → units of 0.1 ns to avoid truncating significant figures.
~500 ns max drift time → 13 bits.

Pad Signal:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
F1	F2	Spare				pad signal (10 fC)									

Pedestal-subtracted (peak – base) signal.
10 bits of ADC information for ~ 10 pC max. integrated charge → units of 10 fC.
The Gains for all the Pads in a chamber will be given for the Pad Signal Correction.

Flag words:

Bit 15 = F1 = if set, missing peak signal (report base)
Bit 14 = F2 = if set, missing base signal (report peak)

2 pad words will always appear for a wire with pad data, and no words for a wire with no pad data.

Note: For PDT's with no hits, the header, alignment words and Hit Wire Count will still be sent to L3, with Hit Wire Count = 0.

Scintillators

General Scintillator Hardware Description

The scintillation counter subsystem includes 48-channel Scintillation Front_End cards (SFE), locted in the VME crates with 8-10 cards per crate. These cards measure the arrival time of scintillation counter signals. Each crate has a Scintillator Readout Controller Card (SCRC) to read the L1 Buffers and a DSP to provide the necessary buffering and formatting. There are 6,000 channels in total and 18 DSPs.
The central C-layer counters ("Cosmic Cap") and central B-layer counters have two phototubes per counter. All other conters have a single phototube each.

For the purpose of L2 formats, only one time is reported for two phototubes/counter.

A scintillation counter's T0 is defined as the mean of a distribution of prompt muons in the center of that counter. Once the position of a track within the pixel is known, light propagation time through the scintillator can be corrected for. The T0-subtracted time for a relativistic particle should ideally be zero, modulo propagation time through detectors. The T0-subtracted time can be slightly negative if a relativistic particle strikes the counter close to the phototube.
For more information on TZeros, refer to the D0Note 3497.

L2 Scintillator Data Format

COMMON HEADER
Phototube address
Time and local phi
Phototube address
Time and local phi
...

Phototube address:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	SFE #								PMT #						
Type =1	Region =0,2,3		Layer =0-2		Octant =0-7			Sub oct							

Type: 0=drift tube, 1=scint
Region: Central=0, N=2, S=3
Suboctant: Most octants are read out by two SFE's, so they each correspond to one suboctant. Only in the A-phi (CMSC-A) system does the division actually split the octant evenly in phi.
SFE#: each SFE in the system has a unique 8-bit number, which is embedded in bits 7-14 of the phototube address. With the bits defined as above, the SFE numbers are (hex):

CMSC-A: 00-0F
CMSC-B: 10-1F
CMSC-C: 20-2F
FMSC-A,N: 80-8F
FMSC-B,N: 90-9F
FMSC-C,N: A0-AF
FMSC-A,S: C0-CF
FMSC-B,S: D0-DF
FMSC-C,S: E0-EF

PMT#: differs for each subsytem.

CMSC-A (A-phi):

6	5	4	3	2	1	0
spare	PMT #					

Phototube readout order and numbering for CMSC A-layer suboctant (similar for bottom A-layer, with last 4 phi segments omitted):

CMSC-A PMT#'s (Decimal):

	z - >								
ϕ | v	0	5	10	16	21	26	32	37	42
	1	6	11	17	22	27	33	38	43
	2	7	12	18	23	28	34	39	44
	3	8	13	19	24	29	35	40	45
	4	9	14	20	25	30	36	41	46

CMSC-A PMT#'s (Hex):

	z - >								
ϕ | v	0	5	A	10	15	1A	20	25	2A
	1	6	B	11	16	1B	21	26	2B
	2	7	C	12	17	1C	22	27	2C
	3	8	D	13	18	1D	23	28	2D
	4	9	E	14	19	1E	24	29	2E

The heavy vertical lines show the PDT boundaries under the counters. So bits 4-5 specify the PDT number. The readout order is also designed so that the gate delays are unique and independent for each set of 15 counters mounted on a single PDT.

CMSC-C (cosmic cap):
(excluding bottom and wall counters)

6	5	4	3	2	1	0
PMT #						
spare	z-index				Phi index	Tube #

The first SFE in an octant will read out 3-PDT's of counters (24 counters = 48 PMT's), and the second will read out 2 PDT's of counters (16 counters = 32 PMT's)

CMSC-C PMT#'s in Hex (example: octant #2):

SFE #	PTD #	ϕ − >	
SFE $24	PDT 202	0,1	2,3
		4,5	6,7
		8,9	A,B
		C,D	E,F
	PDT 212	10,11	12,13
		14,15	16,17
		18,19	1A,1B
		1C,1D	1E,1F
	PDT 222	20,21	22,23
		24,25	26,27
		28,29	2A,2B
		2C,2D	2E,2F
SFE $25	PDT 232	0,1	2,3
		4,5	6,7
		8,9	A,B
		C,D	E,F
	PDT 242	10,11	12,13
		14,15	16,17
		18,19	1A,1B
		1C,1D	1E,1F

CMSC special cases:

The counters mounted on the following PDT's have special geometries that do not follow general scheme of either the A-layer or the C-layer:

SFE	PDTs	description
$1E	107,117,127,137,147	Side B (east)
$18	104,114,124,134,144	Side B (west)
$2A	205	Bottom C
$2B	245	Bottom C
$1A	105,115, west hole	Bottom B + west hole
$1C	106,116,east hole	Bottom B + east hole
$1B	135,145	Bottom B
$1D	136,146	Bottom B
$2C	206	Bottom C
$2D	246	Bottom C

The exact geometry and channel numbering is described in D0note 3642, "Central Muon Upgrade Scintillator Front-End Crate Addresses", by Diehl, Ito, Mao, Podschweit, and Hedin.

FMSC ("pixels"):

6	5	4	3	2	1	0
PMT # (0-$2F)						

Phototube readout order and PMT# for FMSC-C octant 0 (decimal):

R →											
^	First SFE					Second SFE					
|			25	35	45	7	17	27	37	43	46
p		15	24	34	44	6	16	26	36	42	45
h		14	23	33	43	5	15	25	35	41	
i	6	13	22	32	42	4	14	24	34	40	
	5	12	21	31	41	3	13	23	33		
	4	11	20	30	40	2	12	22	32		
	3	10	19	29	39	1	11	21			
	2	9	18	28	38	0	10	20			
	1	8	17	27	37	47	9	19			
	0	7	16	26	36	46	8	18			

Phototube readout order and PMT# for FMSC-C octant 0 (hex):

R →											
^	First SFE					Second SFE					
|			19	23	2D	7	11	1B	25	2B	2E
p		F	18	22	2C	6	10	1A	24	2A	2D
h		E	17	21	2B	5	F	19	23	29	
i	6	D	16	20	2A	4	E	18	22	28	
	5	C	15	1F	29	3	D	17	21		
	4	B	14	1E	28	2	C	16	20		
	3	A	13	1D	27	1	B	15			
	2	9	12	1C	26	0	A	14			
	1	8	11	1B	25	2F	9	13			
	0	7	10	1A	24	2E	8	12			

Phototube readout order and PMT# for FMSC-C octant 1 (decimal):

R →											
^	First SFE						Second SFE				
|	0	7	16	26	36	46	8	18			
p	1	8	17	27	37	47	9	19			
h	2	9	18	28	38	0	10	20			
i	3	10	19	29	39	1	11	21			
	4	11	20	30	40	2	12	22			
	5	12	21	31	41	3	13	23	33		
	6	13	22	32	42	4	14	24	34		
		14	23	33	43	5	15	25	35	41	
		15	24	34	44	6	16	26	36	42	
			25	35	45	7	17	27	37	43	46

Phototube readout order and PMT# for FMSC-C octant 1 (hex):

R →											
^	First SFE						Second SFE				
|	0	7	10	1A	24	2E	8	12			
p	1	8	11	1B	25	2F	9	13			
h	2	9	12	1C	26	0	A	14			
i	3	A	13	1D	27	1	B	15			
	4	B	14	1E	28	2	C	16			
	5	C	15	1F	29	3	D	17	21		
	6	D	16	20	2A	4	E	18	22		
		E	17	21	2B	5	F	19	23	29	
		F	18	22	2C	6	10	1A	24	2A	
			19	23	2D	7	11	1B	25	2B	2E

Note that for the even-numbered octants, the PMT number increases with increasing phi, while for the odd-numbered octants it decreases. There are additional small differences from octant to octant and layers to layer. The complete set of octant cabling schemes is given in D0note #xxxx, "Scintillator Cabling Layout for the D0 Forward Muon System", L. Stutte.

Time and local phi:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
sign	Time (ns/8)											Local phi (2pi/80)			

Time = T0-subtracted time with a sign given by bit 15 (range: -256ns to +256ns)
Local phi = phi offset from beginning of octant.
For two phototubes/counter only one time is reported.

L3 Scintillator Data Format

COMMON HEADER
Hit Channel Count
SFE Count
SFE Address
Reference x/y Offsets
Reference z Offset
ADC_A Data
ADC_B Data
ADC_C Data
PMT #
Time and local phi
PMT #
...
SFE Address
...

Hit Channel Count:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
spare							hit channel count								

Hit channel count: number of phototube channels with hits.
Max. # of channels = (10 SFE's)*(48 channels) = 480 → 9 bits.

SFE Count:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Spare												# of SFE's read out			

Number of active SFE's. Should be a fixed number since every SFE produced ADC data on every event even if it has no hits. Up to 10 SFE's / crate → 4 bits.

SFE Address:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SFE #								SFE hit channel count							
Region =0,2,3		Layer =0-2		Octant =0-7			Sub oct								

Reference x/y Offsets:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
sign	y offset distance (100 μm)							sign	x offset distance (100 μm)						

Distance of reference point for scintillator serviced by this SFE from its nominal position (as defined by geometry constants).
7 bits + 1 sign bit → 0.1 mm resolution over up to +/- 12.7 mm.

Reference z Offset:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Spare								sign	z offset distance (100 μm)						

Distance of reference point for scintillator serviced by this SFE from its nominal position (as defined by geometry constants).
7 bits + 1 sign bit → 0.1 mm resolution over up to +/- 12.7 mm.

ADC Data:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Sub_Chn (0-15)				Pulse Height (fC)											

Pedestal-subtracted pulse height in fC (max should be about 5 pC).
10 bit ADC → 12 bits for conversion without truncating significant figures.

PMT #: Same as for L2.

Time and local phi: Same as for L2, but 1 hit reported for each phototube.

Note:
For scintillator crates with no hits, the alignment and ADC data will still be sent to L3, with hit channel count = 0.

MDT (Mini-drift Tubes) Formats

General MDT Hardware Description

The MDT system has 192-channel Mini-drift tube Digitizing Cards (MDC), located in the VME crates, with up to 12 cards per crate. The cards measure the drift time with low resolution, improving the coordinate resolution of the tubes. Each crate has a MDT Readout Controller (MDRC) to read the L1 Buffers and a DSP to provide necessary buffering and formatting. There are 50,000 channels in total and 24 DSPs.

A MDT tube is a unit with 8 wires. MDT tubes are located in an octant. Each plane consists of 8 octants. There are 3 layers: A, B and C with 4 planes in the A layer and 3 planes each for B and C layers. These layers are located in the North and South side of the detector.

For TZeros, refer to the D0Note 3497.

L2 MDT Data Format

COMMON HEADER
Tube #
Wire Map
Tube #
Wire Map
...

Tube #:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Type =0	Region 2=N,3=S		Layer =0-2		Octant =0-7			r index						Plane “deck”	

A “tube” is an MDT unit with 8 wires.
Wire readout order and numbering for a 4-deck layer (3-deck layers are similar, with z=3 layer omitted):

MDT tube # (bits 0-7) Decimal:

0	4	8	12	16	20	24	28	…	252
1	5	9	13	17	21	25	29	…	253
2	6	10	14	18	22	26	30	…	254
3	7	11	15	19	23	27	31	…	255

MDT tube # (bits 0-7) Hex:

0	4	8	C	10	14	18	1C	…	FC
1	5	9	D	11	15	19	1D	…	FD
2	6	A	E	12	16	1A	1E	…	FE
3	7	B	F	13	17	1B	1F	…	FF

Wire Map:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
spare								Bit map of hit wires in tube							

L3 MDT Data Format

COMMON HEADER
Ref. 1 x/y Offsets
Ref. 1 z/θ Offsets
Ref. 1 ϕ/ψ Offsets
Ref. 2 x/y Offsets
Ref. 2 z/θ Offsets
Ref. 2 ϕ/ψ Offsets
Tube #
Drift times word 1
Drift times word 2
Tube #
Drift times word 1
Drift times word 2
...

Reference 1 x/y Offsets:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
sign	y offset distance (100 μm)							sign	x offset distance (100 μm)						

Distance of reference point for first MDT octant-plane in this module from its nominal position (as defined by geometry constants).
7 bits + 1 sign bit → 0.1 mm resolution over up to +/- 12.7 mm.

Reference 1 z/theta Offsets:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
sign	theta offset (10 μrad)							sign	z offset distance (100 μm)						

z offset: Distance of reference point for first MDT octant-plane in this module from its nominal position (as defined by geometry constants).
7 bits + 1 sign bit → 0.1 mm resolution over up to +/- 12.7 mm.

theta offset: angle of theta reference for first MDT octant-plane in this module with respect to its nominal angle (as defined by geometry constants).
7 bits + 1 sign bit → 0.01 mrad resolution over up to +/- 1.27 mrad.

Reference 1 ϕ/ψ Offsets:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
sign	phi offset (10 μrad)							sign	psi offset (10 μrad)						

phi and psi offsets: angle of phi and psi reference for first MDT octant-plane in this module with respect to its nominal angle (as defined by geometry constants).
7 bits + 1 sign bit → 0.01 mrad resolution over up to +/- 1.27 mrad.

Reference 2 offsets: position and angle offsets for second octant-plane in the module. The word definitions are the same as for the first octant-plane.

Tube #: Same as for L2.

Drift Times Word 1:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
spare	Wire 3 time			spare	Wire 2 time			spare	Wire 1 time			spare	Wire 0 time		

Drift Times Word 2:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
spare	Wire 7 time			spare	Wire 6 time			spare	Wire 5 time			spare	Wire 4 time		

3-bit time resolution over ~1 cm drift distance

Note:
For MDT crates with no hits, the common header and alignment words will still be sent to L3.

MCENs (Muon Cetroids)

Note: The MCEN format is done in hardware rather than in a DSP, but it is included here for completeness. All words shown are 16 bit words.

L2 MCEN Data Format

COMMON HEADER
MCEN hitmap ID #
Hit Map
MCEN hitmap ID #
Hit Map
...

MCEN hitmap ID #:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Type =0	W/C =0	N/ S	Layer =0-2		Octant =0-7			@Mod =0-3		@Segment =0-5				1	1

@Mod = index of 96-bit hitmap
@Segment = a contiguous group of 16 centroids

Hit map:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
16-bit hitmap															

L3 MCEN Data Format

COMMON HEADER
MCEN #1 Word Count
MCEN ID#
MCEN Status Register #1
MCEN Status Register #2
Input data (if 1/n)
Centroid Data
Zero suppressed data
MCEN #2 Word Count
MCEN ID#
MCEN Status Register #1
MCEN Status Register #2
Input data (if 1/n)
Centroid Data
Zero suppressed data
…
MCEN #16 Word Count
MCEN ID#
MCEN Status Register #1
MCEN Status Register #2
Input data (if 1/n)
Centroid Data
Zero suppressed data

MCEN ID #

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	N/S	Layer		Octant			Spare						1	1

Note: Layer=3 is used to denote data from an MCON (concentrator).

Input Data (if 1/n):

Input Channel # 1, word 1
Input Channel #1, word 2
….
Input Channel #1, word 6
Input Channel #2, word 1
…
Input Channel #12, word 6

This is fixed in size, but is only read every 1/n events. Each channel contains data in exactly the same format as it is received from the serial daughterboards.

Centroid Data:

Centroid Channel # 1, bits 0-15
Centroid Channel #1 bits 16-31
Centroid Channel #1 bits 32-47
Centroid Channel #1 bits 48-63
Centroid Channel #1 bits 64-79
Centroid Channel #1 bits 80-95
Centroid Channel #2 bits 0-15
…
Centroid Channel #4 bits 80-95

Zero Suppressed Data:

MCEN hitmap ID #
Hit Map
MCEN hitmap ID #
Hit Map
...

The zero suppressed data is variable in size. There are two words for each non-zero hit map, with the same format as in the L2 data.

Notes on alignment and calibration constants

1. L3 Alignment Constants

One current proposal is to attach "module-wise" alignment constants to the header of each event. Module-wise alignment constants would be the offset of one or a few measured reference coordinates (x, y, z, theta, phi) for each module (PDT; quarter-plane of MDT's; octant of scintillator pixels serviced by one SFE crate) with respect to the nominal reference coordinates defined in the permanent detector geometry file. The geometry file would also hold the information required to translate the reference coordinates into the coordinates of each individual channel (PDT wire; MDT wire; scintillator pixel). The number of reference points will be picked to suit each type of module; e.g.:

- 1 reference point per PDT
- 2 reference points per MDT module (1 per MDT octant-plane)
- 1 reference point per set of scintillator channels served by one SFE (= 5-8 reference points per module; alignment constants would be attached to the SFE "sub-header" containing SFE address and ADC information, and only attached for events in which a given SFE had a hit).

Another proposal is to attach no alignment constants in the DSP.