Data Formats from DSP to L2 & L3

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.

2. TZeroes

T0’s are defined as the reported time in a given detector component for a relativistic particle emanating from the IP on a given crossing. They include particle propagation time (i.e., path length), and signal propagation through electronics, cables, etc. They do not include propagation time through detectors. In particular:

- A PDT’s T0 will be defined as the leading edge of a distribution of all prompt muons in that PDT. PDT drift time and signal propagation time along wires will thus not be subtracted as part of the T0. They will be measured and used to calculate axial and radial positions with respect to wires.

- A MDT's T0 will be defined as the leading edge of a distribution of all prompt muons in that MDT. MDT drift time will thus not be subtracted as part of the T0. It will be used to calculate radial position with respect to wires. Signal propagation time along wires will be considered negligible at this level; in principle, once the axial position of the track within the tube is known, the signal propagation time along the wire could be corrected for.

- A scintillator pixel's T0 will be defined as the mean of a distribution of prompt muons in the center of that pixel. Once the position of a track within the pixel is known, light propagation time through the scintillator can be corrected for.

I.e., the T0-subtracted time for a relativistic particle should ideally be zero, modulo propagation time through detectors.

These are described in more detail in the note on calibration constants.

Common Header Format

Common to L2 and L3 data from all muon subsystems.

Word Count
Module ID
Crossing #
Turn #
Event Status Register
Event Status Register
...

Word Count:

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

Total word count: # of words following this word (potentially arbitrarily large).

Module ID:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
spare						r coord.		η coordinate				ϕ coordinate			

r coord: A-layer = 0
B-layer = 1
C-layer = 2

η coord: PDT = 0-4 (north to south)
CMSC = 5
MDT north = 6
FMSC north = 7
MDT south = 8
FMSC south = 9

ϕ coord: PDT = 0-7
MDT = 0,2,4,6
CMSC & FMSC east = 8
CMSC & FMSC west = 9
MCEN = 8

Crossing #:

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

Local crossing # from readout controller (compared with TFW crossing #; error flag set if they differ).

Turn #:

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

Local turn # from readout controller.

Event Status Register:

Includes:

- Error flags.
- Data type: e.g., “normal”; “all channels”; “calibration”; etc.
- Calibration const. set ID: 11 bits -> up to 2047 sets (~ 2/day for 3 years).
- alignment const. set ID: 6 bits -> up to 63 sets (~10 alignment sets in run 1).
- DSP code version #.
- Other?

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

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

PDT L2 Data Format

COMMON HEADER
Data Word Count
Wire # / Status
Drift dist & Axial dist
Wire # / Status
Drift dist & Axial dist
Wire # / Status
...

Data Word Count:

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

Number of words following this word.
Up to 288 words -> 9 bits.

Wire # / Status:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
spare				status				0	z coordinate				r coord		pair

Wire #: 0-95 (max. 96 wires / PDT) -> 7 bits.
Wire readout order and numbering for a 4-deck PDT (similar scheme for 2- and 3-deck PDT's, with increasing r layers 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	4‘	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

Status: bit 8: 0 = single hit; 1 = multi-hit
bit 9: 1 = missing wire signal
bit 10: 1 = missing pad signal
etc.

Radial Distance:

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

Drift distance perpendicular to wire with respect to wire position; includes T0 subtraction.
1.2 ns TMC bin width over ~500 ns -> 9 bits.
9 bits over ~5 cm -> 100 μm resolution.

Wire Position (θ):

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
spare				angle (mrad)											

Fixed position of wire in terms of theta in global coordinates.
1 mrad resolution over π -> 12 bits.

Longitudinal Position (ϕ):

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
spare			angle (mrad)												

Position along wire in terms of phi in global coordinates.
1.2 ns TMC bin width -> ~20 cm resolution -> ~2 mrad max. resolution; units of mrad to avoid truncating significant figures.
2π coverage -> 13 bits.

PDT L3 Data Format

COMMON HEADER
Reference x/y Offsets
Reference z Offset
Reference θ/ϕ Offsets
Hit Channel Count
Wire # / Status
Time 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 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 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 Theta/Phi Offsets:

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

Theta offset: angle of PDT theta reference with respect to its nominal angle (as defined by geometry constants).
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.

Hit Channel Count:

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

Number of channels with hits.
Max. # of wire/pad channels = (3 CB's)*(32 channels) = 96 -> 7 bits.

Wire # / Status: Same as for L2.

Time Data Word Count:

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

Number of time data words following this word for this wire.
< 8 hits recorded per wire -> 3 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
spare						pad signal (10 fC)									

Pedestal-subtracted signal.
10 bits of ADC information for ~ 10 pC max. integrated charge -> units of 10 fC.
Empty or otherwise flagged word for missing pad signals (i.e., 2 pad words will always appear for PDT's with pads).

Notes:

- For PDT's with no pad connections, the pad signal words will be omitted.

- For PDT's with no hits, the common header, alignment words and hit channel count will still be sent to L3, with hit channel count = 0.

L2 Scintillator Data Format

COMMON HEADER
Data Word Count
PMT #
θ/ϕ Position
Time
PMT #
...

Data Word Count:

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

Number of words following this word.
11 bits to code max # of words: (8 SFE's)*(48 channels)*(3 words) = 1152

Theta/Phi Position:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
phi position (25 mrad)								theta position (25 mrad)							

Position of pixel center in terms of theta and phi in global coordinates.
8 bits over 2π -> units of 25 mrad.

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 bins -> units of 0.1 ns; 132 ns max. time -> 11 bits.

PMT #:
Different for 1- and 2-phototube counters:

1-phototube pixels:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	spare				octant			z coord. (CMSC) or r coord. (FMSC)				ϕ coordinate			

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

Decimal:

	z - >								
	0	16	32	48	64	80	96	112	128
	1	17	33	49	65	81	97	113	129
	2	18	34	50	66	82	98	114	130
ϕ	3	19	35	51	67	83	99	115	131
|	4	20	36	52	68	84	100	116	132
v	5	21	37	53	69	85	101	117	133
	6	22	38	54	70	86	102	118	134
	7	23	39	55	71	87	103	119	135
	8	24	40	56	72	88	104	120	136
	9	25	41	57	73	89	105	121	137

Hex:

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

Phototube readout order and numbering for FMSC octant-plane (decimal):

0	16	32	48	64	80	96	112	128	144	160
1	17	33	49	65	81	97	113	129	145	161
2	18	34	50	66	82	98	114	130	146	
3	19	35	51	67	83	99	115	131	147	
4	20	36	52	68	84	100	116	132		
5	21	37	53	69	85	101	117	133		
6	22	38	54	70	86	102	118	134		
7	23	39	55	71	87	103	119	135		
8	24	40	56	72	88	104	120	136		
9	25	41	57	73	89	105	121	137		

Phototube readout order and numbering for FMSC octant-plane (hex):

0	10	20	30	40	50	60	70	80	90	A0
1	11	21	31	41	51	61	71	81	91	A1
2	12	22	32	42	52	62	72	82	92	
3	13	23	33	43	53	63	73	83	93	
4	14	24	34	44	54	64	74	84		
5	15	25	35	45	55	65	75	85		
6	16	26	36	46	56	66	76	86		
7	17	27	37	47	57	67	77	87		
8	18	28	38	48	58	68	78	88		
9	19	29	39	49	59	69	79	89		

2-phototube pixels:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	spare				octant			z coordinate						ϕ	tube

Phototube readout order and numbering for full CMSC C-layer octant (decimal):

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

Phototube readout order and numbering for full CMSC C-layer octant (hex):

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

L3 Scintillator Data Format

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

Hit Channel Count:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
spare				(# of hit SFE's) - 1			hit channel count								

Hit channel count: number of phototube channels with hits.
Max. # of channels = (8 SFE's)*(48 channels) = 384 -> 9 bits.
Number of hit SFE's gives of # of words of ADC data.
Up to 8 SFE's / crate -> 3 bits.

SFE Address:

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

Max. 8 SFE's / crate -> 3 bits.

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: Same as for L2.

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

L2 MDT Data Format

COMMON HEADER
Data Word Count
Wire #
Wire θ/ϕ Position
Wire #
...

Data Word Count:

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

Number of words following this word.
Up to 2688 words -> 12 bits.

Wire #:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
spare							oct	r coordinate						z coord	

2 octant-planes per module -> 1 bit for octant ID.
Wire readout order and numbering for a 4-deck layer (3-deck layers are similar, with z=3 layer omitted):

Decimal:

0	4	8	12	16	20	24	28	32…	64…	96…	128…	160…	192…	224…
1	5	9	13	17	21	25	29					…		
2	6	10	14	18	22	26	30					…		
3	7	11	15	19	23	27	31	…63	…95	…127	…159	…191	…223	…255

Hex:

0	4	8	C	10	14	18	1C	20…	40…	60…	80…	A0…	C0…	E0…
1	5	9	D	11	15	19	1D	..;	…	…	…	…	…	…
2	6	A	E	12	16	1A	1E	…	…	…	…	…	…	…
3	7	B	F	13	17	1B	1F	…3F	…5F	…7F	…9F	…BF	…DF	…FF

Wire Theta/Phi Position:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
phi position (25 mrad)								theta position (25 mrad)							

Position of wire center in terms of theta and phi in global coordinates.
8 bits over 2π -> units of 25 mrad.

L3 MDT Data Format

COMMON HEADER
Ref. 1 x/y Offsets
Ref. 1 z/θ Offsets
Ref. 1 ϕ / Ref. 2 x Offsets
Ref. 2 y/z Offsets
Ref. 2 θ/ϕ Offsets
Data Word Count
Wire #
Drift Distance
Wire #
...

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 phi / Reference 2 x Offsets:

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

phi offset: angle of phi 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.

x offset: Distance of reference point for second 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 2 y/z Offsets:

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

Distance of reference point for second 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 2 theta/phi Offsets:

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

theta offset: angle of theta reference for second MDT octant-plane in this module with respect to its nominal angle (as defined by geometry constants).
phi offset: angle of phi reference for second 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.

Data Word Count:

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

Number of words following this word.
Up to 2688 * 2 = 5376 words -> 13 bits.

Wire #: Same as for L2.

Drift Distance:

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

Drift distance perpendicular to wire, with respect to wire position.
3-bit time resolution over ~1 cm drift distance -> distance in units of 0.1 mm, to avoid truncating significant figures -> 7 bits.

Note:
For MDT crates with no hits, the common header, alignment words and data word count will still be sent to L3, with data word count = 0.