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Scales for inputs to μGT (φ, η, p_t/E_t, and others)

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With respect to the “legacy” system, the upgraded GT (uGT or μGT) has higher requirements concerning precision and amount of data (more input objects of each kind, additional bits for isolation, quality etc.) and also more input bandwidth and computing resources. The additional resources allow to make the system more uniform and transparent as well as easier to use. The interfaces between uGMT (or μGMT, replacing GMT) and ”Calo Trigger Layer-2” (replacing GCT) have to be defined accordingly.

We are using the new resources as described below (see also proposal [1]; the legacy system’s connections are documented in [2] for muons and in [3] for calo objects) and have introduced the following new features:

1) The hardware allows for 64 bits per muon object and for 32 bits per any other object (jets, e/γ, tau, energy sums).

2) All scales are linear (in the legacy system, the muon p_t scale and the calorimeter η scale were non-linear).

3) All φ scales start at zero (in the legacy system, scales for calo objects started at 350 degrees).

4) Scales are matched to each other so that coarser bins in one system (calo) exactly cover an integer number of smaller bins in another system (muons). The φ and η scales are as far as possible matched to physical boundaries (tower edges) in the calorimeters.

5) The bin width in φ is 2π/576 $\sim$ 0.0109... $\sim$ 0.011 for muons and four times wider (2π/144 $\sim$ 0.0436... $\sim$ 0.044) for all other objects (from calo). These values correspond to 1/8 (for muons) and 1/2 (for calo objects) of a calo tower width in φ.

The bin width in η over the whole η range is 1/8 of 0.0870 for muons and 1/2 of 0.0870 for calo objects (0.0870 is the width of a calo tower in the central rapidity region; at higher pseudorapidity, the physical calo towers get wider). So, for muons the eta bin width is fixed at 0.0870/8=0.010875 while for calo objects it is 0.0870/2=0.0435.

η values, which can be positive or negative, are expressed in Two’s Complement notation:

So, for muons, which use 9 bits for coding η, the central value of the bin 0 (-0.010875/2 to +0.010875/2) = 0.0, the left edge of the bins ranges from $-255 \times 0.010875 - 0.010875/2 = -2.7785625$ to $+255 \times 0.010875 - 0.010875/2 = 2.7676875$. The central value of the bins ranges between ± 2.773125 . The physical η range of the muon detectors is about ± 2.45, so that not all possible η bins are used.

For calo objects, which use 8 bits for coding η, the left edge of the bins range from $-128 \times 0.0435 = -5.568000$ to $127 \times 0.0435 = 5.524500$ (left edge of the bin 0 = 0.0). The central value of the bins ranges between ± 5.546260. The physical η range of the calorimeters is about ± 5, so that not all possible η bins are used.

6) The p_t/E_t scale is identical in step width (0.5 GeV for all systems), starts from 0 (zero) but reaches up to different maximum values for different objects. The highest bin (such as 0x1ff for 9 bits, or 0x7ff for 11 bits, etc.) marks an overflow. Thus, the ranges quoted in Tables 1 and 2 correspond to the right edge (high value) of the second-highest bin.

There is a subtle difference in the p_t/E_t scale for muons as compared to calorimeter objects. While for calorimeter objects an integer value of “zero” in the p_t/E_t entry refers to the lowest p_t/E_t bin (between 0 and 0.5 GeV), for muons this value signifies “no valid muon found”, and the lowest p_t bin (between 0 and 0.5 GeV) for a valid muon is denoted by integer value “one”. Therefore, the p_t range for muons extends to a value that is 0.5 GeV lower than for calorimeter objects with the same number of p_t/E_t bits (such as e/γ or tau).

7) This system allows us to keep a sufficient number of bits for each object free for future use (quality, isolation, possibly tag bits to match uGMT muons to isolation information from the Calorimeter Trigger, etc).

8) For the initial phase, the following numbers of objects are have been implemented: 8 muons, 12 e/γ’s, 12 taus, 12 jets, and 1 each for the energy sums (ET, ETTEM [ECAL sum - part of the ET data structure], ET$_{miss}$, HT, HT$_{miss}$, ET$^{HF}_{miss}$ and HT$^{HF}_{miss}$ [preliminary definition]). “Isolated e/γ’s” do not constitute a separate collection any more but are e/γ’s marked with two ”isolation bit(s)”. ”Forward jets” also are not in a separate collection any more (their η value shows which part of the calorimeter they come from). It is up to the Calorimeter trigger to rank objects in such a way as to guarantee that not all isolated e/γ’s will be killed by non-isolated e/γ’s, or that all central jets will be killed by forward jets.

9) There are ideas to derive electron/gamma signals at high η (beyond the range of ECAL) by using the long and short fibers of HF. Therefore, the e/γ η range has been extended up to η=5, and the number of e/γ objects up to 12. Just as in the case of jets, the Calorimeter trigger will take care that not all central e/γ's are killed by such "forward electrons".

10) The minimum bias HF bits are part of the energy sums data structure. Each of the four quantities ET, ET_{miss}, HT, HT_{miss} contains HF minimum bias bits on the corresponding MSBs (bits 31..28).

11) The "Towercount" bits (introduced for Heavy-Ion running) are part of the HT data structure (bits 24..12).

The following tables (Table 1 and 2) show the bits/resolution per object instance for all objects, including the ones implemented in 2017. "Collection" or "object types" are physical entities such as muons, jets, ET_{miss} etc. "Instances" or "objects" are their individual representatives such as "first muon", "second jet", "third tau" etc.

Table 1: **Scales (muons and individual calorimeter objects)**

object	instances	parameter	range	step	bits
muon	8	φ (extrapolated)	2π	$2\pi/576\sim0.011$	10
		η (extrapolated)	-2.45..2.45	0.0870/8=0.010875	8+1 = 9
		p_t	0..255 GeV	0.5	9
		charge valid			1
		charge sign			1
		quality			4
		iso			2
		index bits			7
		φ (raw, from trackfinder)	2π	$2\pi/576\sim0.011$	10
		η (raw, from trackfinder)	-2.45..2.45	0.0870/8=0.010875	8+1 = 9
		reserved			2
		TOTAL			64
jet	12	φ	2π	$2\pi/144\sim0.044$	8
		η	-5..5	0.0870/2=0.0435	7+1 = 8
		E_t	0..1023.5 GeV	0.5	11
		quality+reserved			5
		TOTAL			32
e/γ	12	φ	2π	$2\pi/144\sim0.044$	8
		η	-5..5	0.0870/2=0.0435	7+1 = 8
		E_t	0..255.5 GeV	0.5	9
		iso			2
		quality+reserved			5
		TOTAL			32
tau	12	φ	2π	$2\pi/144\sim0.044$	8
		η	-5..5	0.0870/2=0.0435	7+1 = 8
		E_t	0..255.5 GeV	0.5	9
		iso			2
		quality+reserved			7
		TOTAL			32

Table 2: **Scales (calorimeter energy sums or "esums")**

object group	instances	parameter	range	step	bits
ET, ETTEM, MBT0HFP	1	E_t [ET]	0..2047.5 GeV	0.5	12
		E_t [ETTEM]	0..2047.5 GeV	0.5	12
		reserved			4
		minimum bias HF	0..15	n.a.	4
		TOTAL			32
HT, TOWERCOUNT, MBT0HFM	1	E_t	0..2047.5 GeV	0.5	12
		TOWERCOUNT	0..8191	1	13
		reserved			3
		minimum bias HF	0..15	n.a.	4
		TOTAL			32
ET$_{miss}$, MBT1HFP	1	φ	2π	2π/144~0.044	8
		E_t	0..2047.5 GeV	0.5	12
		reserved			8
		minimum bias HF	0..15	n.a.	4
		TOTAL			32
HT$_{miss}$, MBT1HFM	1	φ	2π	2π/144~0.044	8
		E_t	0..2047.5 GeV	0.5	12
		reserved			8
		minimum bias HF	0..15	n.a.	4
		TOTAL			32
ET$^{HF}_{miss}$	1	φ	2π	2π/144~0.044	8
		E_t	0..2047.5 GeV	0.5	12
		reserved			12
		TOTAL			32
HT$^{HF}_{miss}$	1	φ	2π	2π/144~0.044	8
(preliminary		E_t	0..2047.5 GeV	0.5	12
definition)		reserved			12
		TOTAL			32

The following pages contain tables showing the data structure of objects and the data flow of objects on the optical links.

- A summary of the optical links is shown in Table 3.

Table 3: **Summary of optical input links**

	link										
frame	0	1	2	3	4	5	6	7	8	9	10
0	free	free	free	free	EG0	EG6	JET0	JET6	TAU0	TAU6	ET, ETTEM, MBT0HFP
1	free	free	free	free	EG1	EG7	JET1	JET7	TAU1	TAU7	HT, TOWERCOUNT, MBT0HFM
2	MU0 [low]	MU2 [low]	MU4 [low]	MU6 [low]	EG2	EG8	JET2	JET8	TAU2	TAU8	ET_{miss}, MBT1HFP
3	MU0 [high]	MU2 [high]	MU4 [high]	MU6 [high]	EG3	EG9	JET3	JET9	TAU3	TAU9	HT_{miss}, MBT1HFM
4	MU1 [low]	MU3 [low]	MU5 [low]	MU7 [low]	EG4	EG10	JET4	JET10	TAU4	TAU10	ET^{HF}_{miss}
5	MU1 [high]	MU3 [high]	MU5 [high]	MU7 [high]	EG5	EG11	JET5	JET11	TAU5	TAU11	HT^{HF}_{miss} (preliminary definition)

- The data structure of a muon object is shown in Table 4 (bits 63..36 are reserved bits).
- The definition of the muon η scale is shown in Table 5. The minimum value is -2.45, the maximum +2.45, so that the highest and lowest bins are ”narrower” than other bins.
- The definition of the muon φ scale is shown in Table 6.
- The definition of the muon quality bits is shown in Table 7. For the time being, the Global Muon Trigger sets the two lowest bits to zero so that the Global Trigger sees effectively only four different qualities. The combination 0xf (binary 1111) has been reserved for possible future use to mark halo muons but this feature has not been implemented in EMTF as of 2017.
- The definition of the muon isolation bits is shown in Table 8. It is preliminary and should be updated when agreed upon.
- The data flow of muon objects on the optical links is shown in Table 9. Frame 0 can probably not be used by the Global Muon Trigger without increasing the latency. It might be possible (but needs to be tested) to use Frame 1 in case more information should have to be transmitted from the Global Muon Trigger to the Global Trigger in the future.

Table 4: **Data structure of a muon object**

bit(s)	parameter
63..62	reserved
61..53	η (raw, from trackfinder)
52..43	φ (raw, from trackfinder)
42..36	index bits
35	charge valid
34	charge sign
33..32	iso
31..23	η (extrapolated to vertex)
22..19	quality
18..10	p_t
9..0	φ (extrapolated to vertex)

Table 5: η **scale of muon objects**

HW index	η range		η bin
0x0E1	2.4414375 to 2.45	224.5∗0.087/8 to 225.5∗0.087/8	225
0x0E0	2.4305625 to 2.4414375	223.5∗0.087/8 to 224.5∗0.087/8	224
...	...	...	...
0x001	0.0054375 to 0.0163125	0.5∗0.087/8 to 1.5∗0.087/8	1
0x000	-0.0054375 to 0.0054375	-0.5∗0.087/8 to 0.5∗0.087/8	0
0x1FF	-0.0163125 to -0.0054375	-1.5∗0.087/8 to -0.5∗0.087/8	-1
0x1FE	-0.0271875 to -0.0054375	-2.5∗0.087/8 to -1.5∗0.087/8	-2
...	...	...	...
0x11F	-2.45 to -2.4414375	-225.5∗0.087/8 to -224.5∗0.087/8	-225

Table 6: φ **scale of muon objects**

HW index	φ range	φ range [degrees]	φ bin
0x000	0 to $2\pi/576$	0 to 0.625	0
0x001	$2\pi/576$ to $2*2\pi/576$	0.625 to 1.250	1
...	...	...	...
0x23F	$575*2\pi/576$ to 2π	359.375 to 360	575

Table 7: **Definition of muon quality bits**

bits [22..19]	definition
0000 0001 0010 0011	no quality requirement
0100 0101 0110 0111	"Open" muon
1000 1001 1010 1011	"Double" muon
1100	"Single" muon
1101	"Single" muon
1110	"Single" muon
1111	halo muon

Table 8: **Definition of muon isolation bits**

bits [33..32]	definition
00	not isolated
01	isolated
10	(to be defined)
11	(to be defined)

Table 9: **Data flow of muon objects 0 and 1 on the optical link** (equivalent for objects 2..7)

frame	objects
0	free (cannot be used)
1	free (could possibly be used in the future)
2	obj. 0, bits 31..0
3	obj. 0, bits 63..32
4	obj. 1, bits 31..0
5	obj. 1, bits 63..32

- The data structure of a jet object is shown in Table 10 (bits 31..27 are not defined yet, they are reserved for isolation, quality and possible future ideas)
- The data structure of an e/γ object is shown in Table 11 (bits 31..27 are not defined yet, they are reserved for quality and possible future ideas)
- The data structure of a tau object is shown in Table 12 (bits 31..27 are not defined yet, they are reserved for quality and possible future ideas)
- The definition of isolation bits for e/γ and tau is shown in Table 13. It is preliminary and should be updated when agreed upon.
- The definition of the calorimeter η scale is shown in Table 14. The minimum value is -5.0, the maximum +5.0. So, the highest and lowest bins are "narrower" than other bins.
- The definition of the φ scale of calorimeter ET$_{miss}$, ET$^{HF}_{miss}$ and HT$_{miss}$ is shown in Table 15.

Table 10: **Data structure of a jet object**

bit(s)	parameter
31..27	reserved
26..19	φ
18..11	η
10..0	E_t

Table 11: **Data structure of an e/γ object**

bit(s)	parameter
31..27	reserved
26..25	iso
24..17	φ
16..9	η
8..0	E_t

Table 12: **Data structure of a tau object**

bit(s)	parameter
31..27	reserved
26..25	iso
24..17	φ
16..9	η
8..0	E_t

Table 13: **Definition of e/γ and tau isolation bits**

bits [26..25]	definition
00	not isolated
01	isolated
10	(to be defined)
11	(to be defined)

Table 14: η **scale of calorimeter objects**

HW index	η range		η bin
0x72	4.959 to 5.0	114$*$0.087/2 to 115$*$0.087/2	114
...	...	...	...
0x01	0.0435 to 0.087	0.087/2 to 2$*$0.087/2	1
0x00	0.0 to 0.0435	0 to 0.087/2	0
0xFF	-0.0435 to 0.0	-0.087/2 to 0	-1
0xFE	-0.087 to -0.0435	-2$*$0.087/2 to -0.087/2	-2
...	...	...	...
0x8E	-5.0 to -4.959	-115$*$0.087/2 to -114$*$0.087/2	-115

Table 15: φ **scale of calorimeter objects, ET$_{miss}$, ET$^{HF}_{miss}$, HT$_{miss}$ (and HT$^{HF}_{miss}$ [preliminary definition])**

HW index	φ range	φ range [degrees]	φ bin
0x00	0 to 2π/144	0 to 2.5	0
0x01	2π/144 to 2$*$2π/144	2.5 to 5.0	1
...	...	...	...
0x8F	143$*$2π/144 to 2π	357.5 to 360	143

- The data flow of e/γ, tau and jet objects 0..5 on an optical link is shown in Table 16.
- The data flow of e/γ, tau and jet objects 6..11 on an optical link is shown in Table 17.

Table 16: **Data flow of e/γ, tau and jet objects 0..5 on optical link**

frame	objects
0	obj. 0
1	obj. 1
2	obj. 2
3	obj. 3
4	obj. 4
5	obj. 5

Table 17: **Data flow of e/γ, tau and jet objects 6..11 on optical link**

frame	objects
0	obj. 6
1	obj. 7
2	obj. 8
3	obj. 9
4	obj. 10
5	obj. 11

- The data flow of energy sums, minimum-bias bits and the TOWERCOUNT variable on the optical link is shown in Table 18.
- The data structures of ET (also including ETTEM and MBT0HFP), HT (also including TOWERCOUNT and MBT0HFM), ET_{miss} (also including MBT1HFP), HT_{miss} (also including MBT1HFM), ET^{HF}_{miss}, ET^{HF}_{miss} and HT^{HF}_{miss} are shown in Tables 19, 20, 21, 22, 23 and 24.
- The definition of minimum bias bits from HF and the definitions of ETTEM and TOWERCOUNT bits are shown in Tables 27, 25 and 26.

Table 18: **Data flow of energy sums on optical link**

frame	objects
0	ET, ETTEM, MBT0HFP
1	HT, TOWERCOUNT, MBT0HFM
2	ET_{miss}, MBT1HFP
3	HT_{miss}, MBT1HFM
4	ET^{HF}_{miss}
5	HT^{HF}_{miss} (preliminary definition)

Table 19: **Data structure of ET** (also including ETTEM and MBT0HFP)

bit(s)	parameter
31..28	minimum bias HF+ threshold 0
27..24	reserved
23..12	E_t [ETTEM]
11..0	E_t [ET]

Table 20: **Data structure of HT** (also including TOWERCOUNT and MBT0HFM)

bit(s)	parameter
31..28	minimum bias HF- threshold 0
27..25	reserved
24..12	TOWERCOUNT
11..0	E_t

Table 21: **Data structure ET$_{miss}$** (also including MBT1HFP)

bit(s)	parameter
31..28	minimum bias HF+ threshold 1
27..20	reserved
19..12	φ
11..0	E_t

Table 22: **Data structure HT$_{miss}$** (also including MBT1HFM)

bit(s)	parameter
31..28	minimum bias HF- threshold 1
27..20	reserved
19..12	φ
11..0	E_t

Table 23: **Data structure ET$^{HF}_{miss}$**

bit(s)	parameter
31..20	reserved
19..12	φ
11..0	E_t

Table 24: **Data structure HT$^{HF}_{miss}$**

bit(s)	parameter
31..20	reserved
19..12	φ (preliminary definition)
11..0	E_t (preliminary definition)

Table 25: **ECAL sum definition (ETTEM)** (in energy sums structure)

objects	acronym	frame	object	bits
ECAL sum	ETTEM	0	ET	23..12

Table 26: **Definition of the "Towercount" variable** (in energy sums structure; introduced for Heavy-Ion running)

objects	acronym	frame	object	bits
Towercount	TOWERCOUNT	1	HT	24..12

Table 27: **Definition of minimum-bias bits from HF** (in energy sums structure)

objects	acronym	frame	objects	bits
minimum bias bit HF+ threshold 0	MBT0HFP	0	ET	31..28
minimum bias bit HF- threshold 0	MBT0HFM	1	HT	31..28
minimum bias bit HF+ threshold 1	MBT1HFP	2	ET$_{miss}$	31..28
minimum bias bit HF- threshold 1	MBT1HFM	3	HT$_{miss}$	31..28

Table 28: **Version history**

Version	Description of Changes	Date
v3	Extended to 12 tau objects [see Table 1]. Updated muon objects with extrapolated φ and η [see Tables 1 and 4]. Updated ”Definition of muon quality bits” [see Table 7]. Added definition of ETTEM, ET^{HF}_{miss} and HT^{HF}_{miss} (preliminary definition) [see item 8) in text and Table 2]. Added definition of the “Towercount” variable [see item 11) in text and Table 2]. Inserted table ”Summary of optical input links” [see Table 3]. Updated Tables 17, 18, 19, 20, 21 and 22. Inserted Tables 23, 24, 25 and 26.	2017/08/07
v2	Changed definition of η scales for calos and muons [see item 5) in text]. Added definition of iso for e/γ and tau objects [see Table 1]. Added definition of minimum bias HF bits [see item 10) in text and Table 1]. Inserted tables for η scale, φ scale, quality and isolation bits of muons. Inserted tables for η scale and φ scale of calos. Inserted table for minimum bias HF definition. `http://cms.cern.ch/iCMS/jsp/openfile.jsp?tp=draft&files=DN2014_029_v2.pdf`	2016/05/30
v1	Document created. `http://cms.cern.ch/iCMS/jsp/openfile.jsp?tp=draft&files=DN2014_029_v1.pdf`	2014/09/11

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