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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.

Remark: Muon η and φ raw bits currently not used in uGT. Muon φ raw bits [φ (out)] are part of the 64 bit muon structure on frames 2 to 6, η raw bits are transmitted on frame 1 (see Table 3).

6) The p_t/E_t scale for calo and energy sums objects 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.
The p_t scale for muon objects starts from 0 (zero), but HW index=0 indicates an invalid muon, HW index=1 represents 0 to 0.5 GeV, the step width is 0.5 GeV. The highest bin 0x1ff (for 9 bits) marks an overflow.

7) The new muon structure contains:
- ”unconstrained p_t” scale (8 bits) in steps of 1.0 GeV starting from 0 (zero), HW index=0 indicates an invalid muon, the highest bin 0xff marks an overflow.
- ”impact parameter” with 2 bits.
- ”hadronic shower trigger (mus)” bits on bit 31 of MU0, MU2, MU3, MU4 and MU6 objects.

8) The new jet structure contains:
- bit 27 will be used to flag a jet as delayed / displaced based on HCAL timing and depth profiles that are indicative of a LLP decay. This bit is referred to as DISP. If this bit is set to 1, then the jet has been tagged as an LLP jet.

9) 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).

10) 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$^{HF}_{miss}$). "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 be 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.

11) 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".

12) 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).

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

14) The "Asymmetry" and "Centrality" bits (introduced for Heavy-Ion running) are part of the ET$_{miss}$, HT$_{miss}$, ET$^{HF}_{miss}$ and HT$^{HF}_{miss}$ data structure.

The following tables (Table 1 and 2) show the bits/resolution per object instance for all objects, including the ones that will be 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 (muon and calorimeter)**

object	collections × instances	parameter	range	step	bits
muon	1 * 8	φ (extrapolated)	2π	2π/576∼0.011	10
		p_t	0..256 GeV	0.5	9
		quality			4
		η (extrapolated)	-2.45..2.45	0.0870/8=0.010875	8+1 = 9
		iso			2
		charge sign			1
		charge valid			1
		index bits			7
		φ (out)	2π	2π/576∼0.011	10
		unconstrained p_t	0..256 GeV	1.0	8
		hadronic shower trigger			1
		impact parameter			2
		TOTAL			64
jet	1 * 12	E_t	0..1024 GeV	0.5	11
		η	-5..5	0.0870/2=0.0435	7+1 = 8
		φ	2π	2π/144∼0.044	8
		DISP			1
		quality flags			2
		spare			2
		TOTAL			32
e/γ	1 * 12	E_t	0..256 GeV	0.5	9
		η	-5..5	0.0870/2=0.0435	7+1 = 8
		φ	2π	2π/144∼0.044	8
		iso			2
		spare			5
		TOTAL			32
tau	1 * 12	E_t	0..256 GeV	0.5	9
		η	-5..5	0.0870/2=0.0435	7+1 = 8
		φ	2π	2π/144∼0.044	8
		iso			2
		spare			5
		TOTAL			32

Table 2: **Scales (esums)**

object	collections × instances	parameter	range	step	bits
ET	1 * 1	E_t [ET]	0..2048 GeV	0.5	12
		E_t [ETTEM]	0..2048 GeV	0.5	12
		spare			4
		minimum bias HF	0..15	n.a.	4
		TOTAL			32
HT	1 * 1	E_t	0..2048 GeV	0.5	12
		TOWERCOUNT	0..8191	1	13
		spare			3
		minimum bias HF	0..15	n.a.	4
		TOTAL			32
ET$_{miss}$	1 * 1	E_t	0..2048 GeV	0.5	12
		φ	2π	2π/144$\sim$0.044	8
		ASYMET	0..255	1	8
		minimum bias HF	0..15	n.a.	4
		TOTAL			32
HT$_{miss}$	1 * 1	E_t	0..2048 GeV	0.5	12
		φ	2π	2π/144$\sim$0.044	8
		ASYMHT	0..255	1	8
		minimum bias HF	0..15	n.a.	4
		TOTAL			32
ET$_{miss}^{HF}$	1 * 1	E_t	0..2048 GeV	0.5	12
		φ	2π	2π/144$\sim$0.044	8
		ASYMETHF	0..255	1	8
		CENT[3:0]	4 bits		4
		TOTAL			32
HT$_{miss}^{HF}$ (preliminary definition)	1 * 1	E_t	0..2048 GeV	0.5	12
		φ	2π	2π/144$\sim$0.044	8
		ASYMHTHF	0..255	1	8
		CENT[7:4]	4 bits		4
		TOTAL			32

The following pages contain tables for 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. (Remark: Muon eta raw bits currently not used in uGT!)

Table 3: **Summary of optical 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	MU0 eta raw on bits 21:13 MU1 eta raw on bits 30:22	MU2 eta raw on bits 21:13 MU3 eta raw on bits 30:22	MU4 eta raw on bits 21:13 MU5 eta raw on bits 30:22	MU6 eta raw on bits 21:13 MU7 eta raw on bits 30:22	EG1	EG7	JET1	JET7	TAU1	TAU7	HT, TOWERCOUNT, MBT0HFM
2	MU0 [31:00]	MU2 [31:00]	MU4 [31:00]	MU6 [31:00]	EG2	EG8	JET2	JET8	TAU2	TAU8	ET_{miss}, ASYMET, MBT1HFP
3	MU0 [63:32]	MU2 [63:32]	MU4 [63:32]	MU6 [63:32]	EG3	EG9	JET3	JET9	TAU3	TAU9	HT_{miss}, ASYMHT, MBT1HFM
4	MU1 [31:00]	MU3 [31:00]	MU5 [31:00]	MU7 [31:00]	EG4	EG10	JET4	JET10	TAU4	TAU10	ET^{HF}_{miss} ASYMETHF, CENT[3:0]
5	MU1 [63:32]	MU3 [63:32]	MU5 [63:32]	MU7 [63:32]	EG5	EG11	JET5	JET11	TAU5	TAU11	HT^{HF}_{miss} ASYMHTHF, CENT[7:4]

- The data structure of a muon object is shown in Table 4.
- The definition of the muon η scale shown in Table 5. The minimum value is -2.45, the maximum +2.45, so the the highest and lowest bins are ”narrower” than other bins.
- The definition of the muon φ scale shown in Table 6.
- The definition of the muon quality bits is shown in Table 7. It is preliminary, quality “level x” should be replaced by reliable terms.
- The definition of the muon isolation bits is shown in Table 10. It is preliminary and should be updated when agreed upon.
- The data flow of muon objects on the optical links is shown in Table 11.

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

bit(s)	parameter
63..62	impact parameter
61	hadronic shower (mus), on MU0, MU2, MU3, MU4 and MU6
60..53	unconstrained p_t
52..43	φ (out)
42..36	index bits
35	charge valid
34	charge sign
33..32	iso
31..23	η (extrapolated)
22..19	quality
18..10	p_t
9..0	φ (extrapolated)

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 2π/576	0 to 0.625	0
0x001	2π/576 to 2∗2π/576	0.625 to 1.250	1
...	...	...	...
0x23F	575∗2π/576 to 2π	359.375 to 360	575

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

bits [22..19]	definition
0000	quality ”level 0”
0001	quality ”level 1”
0010	quality ”level 2”
0011	quality ”level 3”
0100	quality ”level 4”
0101	quality ”level 5”
0110	quality ”level 6”
0111	quality ”level 7”
1000	quality ”level 8”
1001	quality ”level 9”
1010	quality ”level 10”
1011	quality ”level 11”
1100	quality ”level 12”
1101	quality ”level 13”
1110	quality ”level 14”
1111	quality ”level 15”

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

bits [33..32]	definition
00	not isolated
01	isolated
10	TBD
11	TBD

Table 9: **Definition of hadronic shower (mus) bits**

muon object	hadronic shower (on bit 61)
0	MUS0
2	MUS1
3	MUS2
4	MUSOOT0
6	MUSOOT1

Table 10: **Definition of muon impact parameter**

bits [63..62]	definition
00	TBD
01	TBD
10	TBD
11	TBD

Table 11: **Data flow of muon objects 0 and 1 on the optical link** (equivalent for objects 2..7)

frame	objects
0	free
1	free
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 12 (bits 31..30 spare bits)
- The data structure of an e/γ object is shown in Table 13 (bits 31..27 are not defined yet)
- The data structure of a tau object is shown in Table 14 (bits 31..27 are not defined yet)
- The definition of isolation bits for e/γ and tau is shown in Table 15.
- The definition of the calorimeter η scale is shown in Table 16. The minimum value is -5.0, the maximum +5.0, so the the highest and lowest bins are ”narrower” other bins.
- The definition of the calorimeter ET$_{miss}$, ET$^{HF}_{miss}$ and HT$_{miss}$ φ scale is shown in Table 17.

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

bit(s)	parameter
31..30	spare
29..28	quality flags
27..27	DISP
26..19	φ
18..11	η
10..0	E_t

Table 13: **Data structure of an e/γ object**

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

Table 14: **Data structure of a tau object**

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

Table 15: **Definition of e/γ and tau isolation bits**

bits [26..25]	definition
00	not isolated
01	isolated
10	TBD
11	TBD

Table 16: 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 17: 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 $2\pi/144$	0 to 2.5	0
0x01	$2\pi/144$ to $2*2\pi/144$	2.5 to 5.0	1
...	...	...	...
0x8F	$143*2\pi/144$ 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 18.
- The data flow of e/γ, tau and jet objects 6..11 on an optical link is shown in Table 19.

Table 18: **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 19: **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 on the optical link is shown in Table 20.
- The data structure of ET (including ETTEM and MBT0HFP), HT (including TOWERCOUNT and MBT0HFM), ET$_{miss}$ (including MBT1HFP), HT$_{miss}$ (including MBT1HFM), ET$^{HF}_{miss}$ ET$^{HF}_{miss}$ and HT$^{HF}_{miss}$ is shown in Tables 21, 22, 23, 24, 25 and 26.
- The definition of minimum bias HF, ETTEM, TOWERCOUNT, Asymmetry and Centrality bits is shown in 29, 27, 28 30 and 31.

Table 20: **Data flow of energy sums on optical link**

frame	objects
0	ET, ETTEM, MBT0HFP
1	HT, TOWERCOUNT, MBT0HFM
2	ET$_{miss}$, ASYMET, MBT1HFP
3	HT$_{miss}$, ASYMHT, MBT1HFM
4	ET$^{HF}_{miss}$, ASYMETHF, CENT[3:0]
5	HT$^{HF}_{miss}$, ASYMHTHF, CENT[7:4]

Table 21: **Data structure of ET** (including ETTEM and MBT0HFP)

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

Table 22: **Data structure of HT** (including TOWERCOUNT and MBT0HFM)

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

Table 23: **Data structure ET$_{miss}$** (including MBT1HFP)

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

Table 24: **Data structure HT$_{miss}$** (including MBT1HFM)

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

Table 25: **Data structure ET$^{HF}_{miss}$**

bit(s)	parameter
31..28	CENT[3:0]
27..20	ASYMETHF
19..12	φ
11..0	E_t

Table 26: **Data structure HT$^{HF}_{miss}$**

bit(s)	parameter
31..28	CENT[7:4]
27..20	ASYMHTHF
19..12	φ
11..0	E_t

Table 27: **ECAL sum definition (ETTEM)** (in energy sums structure)

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

Table 28: **Definition of "Towercount"** (in energy sums structure; introduced for Heavy-Ion running)

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

Table 29: **Minimum bias HF definition** (in energy sums structure)

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

Table 30: **"Asymmetry" definition** (in energy sums structure)

objects	acronym	frame	objects	bits
Asymmetry of ET	ASYMET	2	ET_{miss}	27..20
Asymmetry of HT	ASYMHT	3	HT_{miss}	27..20
Asymmetry of ETHF	ASYMETHF	4	ET_{miss}^{HF}	27..20
Asymmetry of HTHF	ASYMHTHF	5	HT_{miss}^{HF}	27..20

Table 31: **"Centrality" definition** (in energy sums structure)

objects	acronym	frame	objects	bits
Centrality bits [3:0]	CENT[3:0]	4	ET_{miss}^{HF}	31..28
Centrality bits [7:4]	CENT[7:4]	5	HT_{miss}^{HF}	31..28

References

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