3 August 2020

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

H.Bergauer, J.Erö, M.Jeitler, J.Wittmann, C.-E.Wulz

Institute of High Energy Physics of the Austrian Academy of Sciences

C.Foudas

University of Ioánnina, Greece

K.Bunkowski, M.Konecki

University of Warsaw, Poland

L.Uvarov

INP, St. Petersburg, Russia

C.Battilana, D.Rabady, H.Sakulin

CERN, Geneva, Switzerland

J.Brooke

University of Bristol, UK

G.Iles, A.Tapper

Imperial College, London, UK

D.Acosta, I.Furic, A.Madorsky

University of Florida, Gainesville, USA

M.Matveev, P.Padley

Rice University, Houston, USA

P.Klabbers, W.H.Smith

Department of Physics, University of Wisconsin, Madison, WI, USA

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.

The new muon structure contains:
- ”unconstraint p_t” scale (8 bits) in steps of 1.0 GeV starting from 0 (zero), the highest bin 0xff marks an overflow.
- ”impact parameter” with 2 bits.

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$^{HF}_{miss}$). “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.

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).

12) 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 $\times$ instances	parameter	range	step	bits
muon	1 * 8	φ (extrapolated)	2π	2π/576$\sim$0.011	10
		p_t	0..256 GeV	0.5	9
		quality			4
		η (extrapolated)	-2.45..2.45	0.0870/8=0.010875	8+1 = 9
		iso			2
		charge sign			1
		charge valid			1
		index bits			7
		φ (out)	2π	2π/576$\sim$0.011	10
		unconatraint p_t	0..256 GeV	1.0	8
		reserved			1
		impact parameter			2
		TOTAL			64
jet	1 * 12	E_t	0..1024 GeV	0.5	11
		η	-5..5	0.0870/2=0.0435	7+1 = 8
		φ	2π	2π/144$\sim$0.044	8
		reserved			5
		TOTAL			32
e/γ	1 * 12	E_t	0..256 GeV	0.5	9
		η	-5..5	0.0870/2=0.0435	7+1 = 8
		φ	2π	2π/144$\sim$0.044	8
		iso			2
		reserved			5
		TOTAL			32
tau	1 * 12	E_t	0..256 GeV	0.5	9
		η	-5..5	0.0870/2=0.0435	7+1 = 8
		φ	2π	2π/144$\sim$0.044	8
		iso			2
		reserved			5
		TOTAL			32

Table 2: **Scales (esums)**

object	collections $\times$ 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
		reserved			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
		reserved			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.

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	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}, ASYMET, MBT1HFP
3	MU0 [high]	MU2 [high]	MU4 [high]	MU6 [high]	EG3	EG9	JET3	JET9	TAU3	TAU9	HT_{miss}, ASYMHT, MBT1HFM
4	MU1 [low]	MU3 [low]	MU5 [low]	MU7 [low]	EG4	EG10	JET4	JET10	TAU4	TAU10	ET_{miss}^{HF} ASYMETHF, CENT[3:0]
5	MU1 [high]	MU3 [high]	MU5 [high]	MU7 [high]	EG5	EG11	JET5	JET11	TAU5	TAU11	HT_{miss}^{HF} ASYMHTHF, CENT[7:4]

- 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 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 9. It is preliminary and should be updated when agreed upon.
- The data flow of muon objects on the optical links is shown in Table 10.

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

bit(s)	parameter
63..62	impact parameter
61	reserved
60..53	unconstraint 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 $2\pi/576$	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	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 muon impact parameter**

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

Table 10: **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 11 (bits 31..27 are not defined yet, reserved for isolation, quality and reserved)
- The data structure of an e/γ object is shown in Table 12 (bits 31..27 are not defined yet, reserved for quality and reserved)
- The data structure of a tau object is shown in Table 13 (bits 31..27 are not defined yet, reserved for quality and reserved)
- The definition of isolation bits for e/γ and tau is shown in Table 14. It is preliminary and should be updated when agreed upon.
- The definition of the calorimeter η scale is shown in Table 15. 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 16.

Table 11: **Data structure of a jet object**

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

Table 12: **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 13: **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 14: **Definition of e/γ and tau isolation bits**

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

Table 15: 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 16: 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 17.
- The data flow of e/γ, tau and jet objects 6..11 on an optical link is shown in Table 18.

Table 17: **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 18: **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 19.
- 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 20, 21, 22, 23, 24 and 25.
- The definition of minimum bias HF, ETTEM, TOWERCOUNT, Asymmetry and Centrality bits is shown in 28, 26, 27 29 and 30.

Table 19: **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 20: **Data structure of ET** (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 21: **Data structure of HT** (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 22: **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 23: **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 24: **Data structure ET$^{HF}_{miss}$**

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

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

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

Table 26: **ECAL sum definition (ETTEM)** (in energy sums structure)

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

Table 27: **Definition of "Towercount"** (in energy sums structure; introduced for Heavy-Ion running)

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

Table 28: **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 29: **"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 30: **"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

[1] https://indico.cern.ch/getFile.py/access?contribId=4&sessionId=0&resId=0&materialId=slides&confId=206223

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