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# Scales for inputs to $\mu$GT ($\varphi$, $\eta$, $p_t/E_t$, and others)


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With respect to the "legacy" system, the upgraded GT (uGT or $\mu$GT) 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 $\mu$GMT, 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/$\gamma$, tau, energy sums).

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

3) All $\varphi$ 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 $\varphi$ and $\eta$ scales are as far as possible matched to physical boundaries (tower edges) in the calorimeters.

5) The bin width in $\varphi$ is $2\pi$/576 $\sim$ 0.0109... $\sim$ 0.011 for muons and four times wider ($2\pi$/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 $\varphi$.

The bin width in $\eta$ over the whole $\eta$ 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.

$\eta$ values, which can be positive or negative, are expressed in Two's Complement notation:

So, for muons, which use 9 bits for coding $\eta$, 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 $\pm 2.773125$ . The physical $\eta$ range of the muon detectors is about $\pm 2.45$, so that not all possible $\eta$ bins are used.

For calo objects, which use 8 bits for coding $\eta$, 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 $\pm 5.546260$. The physical $\eta$ range of the calorimeters is about $\pm 5$, so that not all possible $\eta$ bins are used.

**Remark:** Muon $\eta$ and $\varphi$ raw bits currently not used in uGT. Muon $\varphi$ raw bits [$\varphi$ (out)] are part of the 64 bit muon structure on frames 2 to 6, $\eta$ 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, 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/$\gamma$'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/$\gamma$'s" do not constitute a separate collection any more but are e/$\gamma$'s marked with two "isolation bit(s)". "Forward jets" also are not in a separate collection any more (their $\eta$ 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/$\gamma$'s will be killed by non-isolated e/$\gamma$'s, or that all central jets will be killed by forward jets.

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

15) The "CICADA" data structure with 6 "Boosted jets" (bjets) and values for Anomaly Detection and Heavy Ion bits [4].

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 | $\varphi$ (extrapolated) | $2\pi$ | $2\pi$/576$\sim$0.011 | 10 |
| | | $p_t$ | 0..256 GeV | 0.5 | 9 |
| | | quality | | | 4 |
| | | $\eta$ (extrapolated) | -2.45..2.45 | 0.0870/8=0.010875 | 8+1 = 9 |
| | | iso | | | 2 |
| | | charge sign | | | 1 |
| | | charge valid | | | 1 |
| | | index bits | | | 7 |
| | | $\varphi$ (out) | $2\pi$ | $2\pi$/576$\sim$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 |
| | | $\eta$ | -5..5 | 0.0870/2=0.0435 | 7+1 = 8 |
| | | $\varphi$ | $2\pi$ | $2\pi$/144$\sim$0.044 | 8 |
| | | DISP | | | 1 |
| | | quality flags | | | 2 |
| | | spare | | | 2 |
| | | TOTAL | | | 32 |
| bjet | 1 * 6 | $E_t$ | 0..1024 GeV | 0.5 | 11 |
| | | $\eta$ | -5..5 | 0.0870/2=0.0435 | 7+1 = 8 |
| | | $\varphi$ | $2\pi$ | $2\pi$/144$\sim$0.044 | 8 |
| | | flag | | | 1 |
| | | AD value, HI bits | | | 4 |
| | | TOTAL | | | 32 |
| e/$\gamma$ | 1 * 12 | $E_t$ | 0..256 GeV | 0.5 | 9 |
| | | $\eta$ | -5..5 | 0.0870/2=0.0435 | 7+1 = 8 |
| | | $\varphi$ | $2\pi$ | $2\pi$/144$\sim$0.044 | 8 |
| | | iso | | | 2 |
| | | spare | | | 5 |
| | | TOTAL | | | 32 |
| tau | 1 * 12 | $E_t$ | 0..256 GeV | 0.5 | 9 |
| | | $\eta$ | -5..5 | 0.0870/2=0.0435 | 7+1 = 8 |
| | | $\varphi$ | $2\pi$ | $2\pi$/144$\sim$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 |
| | | $\varphi$ | 2$\pi$ | 2$\pi$/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 |
| | | $\varphi$ | 2$\pi$ | 2$\pi$/144$\sim$0.044 | 8 |
| | | ASYMHT | 0..255 | 1 | 8 |
| | | minimum bias HF | 0..15 | n.a. | 4 |
| | | TOTAL | | | 32 |
| ET$^{HF}_{miss}$ | 1 * 1 | $E_t$ | 0..2048 GeV | 0.5 | 12 |
| | | $\varphi$ | 2$\pi$ | 2$\pi$/144$\sim$0.044 | 8 |
| | | ASYMETHF | 0..255 | 1 | 8 |
| | | CENT[3:0] | 4 bits | | 4 |
| | | TOTAL | | | 32 |
| HT$^{HF}_{miss}$ (preliminary definition) | 1 * 1 | $E_t$ | 0..2048 GeV | 0.5 | 12 |
| | | $\varphi$ | 2$\pi$ | 2$\pi$/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 (part 1)**

| | link | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| frame | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 0 | free | free | free | free | EG0 | EG6 | JET0 | JET6 | TAU0 | TAU6 |
| 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 |
| 2 | MU0 [31:00] | MU2 [31:00] | MU4 [31:00] | MU6 [31:00] | EG2 | EG8 | JET2 | JET8 | TAU2 | TAU8 |
| 3 | MU0 [63:32] | MU2 [63:32] | MU4 [63:32] | MU6 [63:32] | EG3 | EG9 | JET3 | JET9 | TAU3 | TAU9 |
| 4 | MU1 [31:00] | MU3 [31:00] | MU5 [31:00] | MU7 [31:00] | EG4 | EG10 | JET4 | JET10 | TAU4 | TAU10 |
| 5 | MU1 [63:32] | MU3 [63:32] | MU5 [63:32] | MU7 [63:32] | EG5 | EG11 | JET5 | JET11 | TAU5 | TAU11 |

Table 4: **Summary of optical links (part 2)**

| | link | | | | | | |
|---|---|---|---|---|---|---|---|
| frame | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| 0 | ET, ETTEM, MBT0HFP | res. (ZDC) | ExtCond [31:0] | ExtCond [95:64] | ExtCond [159:128] | ExtCond [223:192] | BJET0, Anomaly Detection - Integer high |
| 1 | HT, TOWERCOUNT, MBT0HFM | res. (ZDC) | ExtCond [63:32] | ExtCond [127:96] | ExtCond [191:160] | ExtCond [255:224] | BJET1, Anomaly Detection - Integer low |
| 2 | $\mathrm{ET}_{miss}$, ASYMET, MBT1HFP | res. (ZDC) | free | free | free | free | BJET2, Anomaly Detection - Decimal high |
| 3 | $\mathrm{HT}_{miss}$, ASYMHT, MBT1HFM | res. (ZDC) | free | free | free | free | BJET3, Anomaly Detection - Decimal low |
| 4 | $\mathrm{ET}_{miss}^{HF}$ ASYMETHF, CENT[3:0] | res. (ZDC) | free | free | free | free | BJET4, Heavy Ion bits - high |
| 5 | $\mathrm{HT}_{miss}^{HF}$ ASYMHTHF, CENT[7:4] | res. (ZDC) | free | free | free | free | BJET5, Heavy Ion bits - low |

- The data structure of a muon object is shown in Table 5.
- The definition of the muon $\eta$ scale shown in Table 6. 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 $\varphi$ scale shown in Table 7.

- The definition of the muon quality bits is shown in Table 8. It is preliminary, quality “level x” should be replaced by reliable terms.
- The definition of the muon isolation bits is shown in Table 11. It is preliminary and should be updated when agreed upon.
- The data flow of muon objects on the optical links is shown in Table 12.

Table 5: **Data structure of a muon object**

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

Table 6: $\eta$ **scale of muon objects**

| HW index | $\eta$ range | | $\eta$ 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 7: $\varphi$ **scale of muon objects**

| HW index | $\varphi$ range | $\varphi$ range [degrees] | $\varphi$ 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$/576 to 2$\pi$ | 359.375 to 360 | 575 |

Table 8: **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 9: **Definition of muon isolation bits**

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

Table 10: **Definition of hadronic shower (mus) bits**

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

Table 11: **Definition of muon impact parameter**

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

Table 12: **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 13 (bits 31..30 spare bits)
- The data structure of a bjet object is shown in Table 14 (bits 31..28 used for Anomaly Detection and Heavy Ion bits)
- The data structure of an e/$\gamma$ object is shown in Table 15 (bits 31..27 are not defined yet)
- The data structure of a tau object is shown in Table 16 (bits 31..27 are not defined yet)
- The definition of isolation bits for e/$\gamma$ and tau is shown in Table 17.
- The definition of the calorimeter $\eta$ scale is shown in Table 18. 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$_{miss}$ $\varphi$ scale is shown in Table 19.

Table 13: **Data structure of a jet object**

| bit(s) | parameter |
|---|---|
| 31..30 | spare |
| 29..28 | quality flags |
| 27..27 | DISP |
| 26..19 | $\varphi$ |
| 18..11 | $\eta$ |
| 10..0 | $E_t$ |

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

| bit(s) | parameter |
|---|---|
| 31..28 | Anomaly Detection and Heavy Ion bits |
| 27..27 | flag |
| 26..19 | $\varphi$ |
| 18..11 | $\eta$ |
| 10..0 | $E_t$ |

Table 15: **Data structure of an e/$\gamma$ object**

| bit(s) | parameter |
|---|---|
| 31..27 | spare |
| 26..25 | iso |
| 24..17 | $\varphi$ |
| 16..9 | $\eta$ |
| 8..0 | $E_t$ |

Table 16: **Data structure of a tau object**

| bit(s) | parameter |
|---|---|
| 31..27 | spare |
| 26..25 | iso |
| 24..17 | $\varphi$ |
| 16..9 | $\eta$ |
| 8..0 | $E_t$ |

Table 17: **Definition of e/$\gamma$ and tau isolation bits**

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

Table 18: $\eta$ **scale of calorimeter objects**

| HW index | $\eta$ range | | $\eta$ bin |
|---|---|---|---|
| 0x72 | 4.959 to 5.0025 | 114$*$0.087/2 to 115$*$0.087/2 | 114 |
| ... | ... | ... | ... |
| 0x01 | 0.0435 to 0.087 | 0.087/2 to 2$*$0.087/2 | 1 |
| 0x00 | 0.0 to 0.0435 | 0 to 0.087/2 | 0 |
| 0xFF | -0.0435 to 0.0 | -0.087/2 to 0 | -1 |
| 0xFE | -0.087 to -0.0435 | -2$*$0.087/2 to -0.087/2 | -2 |
| ... | ... | ... | ... |
| 0x8D | -5.0025 to -4.959 | -115$*$0.087/2 to -114$*$0.087/2 | -115 |

Table 19: $\varphi$ **scale of calorimeter objects, ET$_{miss}$, ET$^{HF}_{miss}$, HT$_{miss}$ (and HT$^{HF}_{miss}$ [preliminary definition])**

| HW index | $\varphi$ range | $\varphi$ range [degrees] | $\varphi$ 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$/144 to 2$\pi$ | 357.5 to 360 | 143 |

- The data flow of e/$\gamma$, tau and jet objects 0..5 on an optical link is shown in Table 20.
- The data flow of e/$\gamma$, tau and jet objects 6..11 on an optical link is shown in Table 21.

Table 20: **Data flow of e/$\gamma$, 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 21: **Data flow of e/$\gamma$, 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 22.
- The data structure of ET (including ETTEM and MBT0HFP), HT (including TOWERCOUNT and MBT0HFM), $\text{ET}_{miss}$ (including MBT1HFP), $\text{HT}_{miss}$ (including MBT1HFM), $\text{ET}^{HF}_{miss}$ $\text{ET}^{HF}_{miss}$ and $\text{HT}^{HF}_{miss}$ is shown in Tables 23, 24, 25, 26, 27 and 28.
- The definition of minimum bias HF, ETTEM, TOWERCOUNT, Asymmetry and Centrality bits is shown in 31, 29, 30 32 and 33.
- The definition of CICADA bits is shown in 34 and 14.

Table 22: **Data flow of energy sums on optical link**

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

Table 23: **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 24: **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 25: **Data structure ET**$_{miss}$ (including MBT1HFP)

| bit(s) | parameter |
|---|---|
| 31..28 | minimum bias HF+ threshold 1 |
| 27..20 | ASYMET |
| 19..12 | $\varphi$ |
| 11..0 | $E_t$ |

Table 26: **Data structure HT**$_{miss}$ (including MBT1HFM)

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

Table 27: **Data structure ET**$^{HF}_{miss}$

| bit(s) | parameter |
|---|---|
| 31..28 | CENT[3:0] |
| 27..20 | ASYMETHF |
| 19..12 | $\varphi$ |
| 11..0 | $E_t$ |

Table 28: **Data structure HT**$^{HF}_{miss}$

| bit(s) | parameter |
|---|---|
| 31..28 | CENT[7:4] |
| 27..20 | ASYMHTHF |
| 19..12 | $\varphi$ |
| 11..0 | $E_t$ |

Table 29: **ECAL sum definition (ETTEM)** (in energy sums structure)

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

Table 30: **Definition of "Towercount"** (in energy sums structure; introduced for Heavy-Ion running)

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

Table 31: **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 32: **"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 33: **"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 |

Table 34: **CICADA data on optical link**

| frame | 31..28 | 27..0 |
|---|---|---|
| 0 | Anomaly Detection Integer MSB | Boosted jet (bjet) 1 |
| 1 | Anomaly Detection Integer LSB | Boosted jet (bjet) 2 |
| 2 | Anomaly Detection Decimal MSB | Boosted jet (bjet) 3 |
| 3 | Anomaly Detection Decimal LSB | Boosted jet (bjet) 4 |
| 4 | Heavy Ion MSB | Boosted jet (bjet) 5 |
| 5 | Heavy Ion LSB | Boosted jet (bjet) 6 |

# References

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