Algorithms and data content for L1Topo

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Introduction

This is a working document with the purpose of specifying input and output data and functional algorithm blocks for the Level-1 topological processor (L1Topo).

Topology algorithms

In this section we present lists of potential topological algorithms under consideration for L1Topo. The focus so far on algorithm studies has been on objects from L1Calo (e/gamma, tau, jets, and missing ET vector), but the algorithm tools can be easily extended to include RoIs from eFEX, jFEX and L1Muon.

The algorithms listed below include comments on the types of objects taken as inputs by the tool, as well as and other related information. Algorithm inputs labeled x or y indicates any single lepton (l), jet (t) or missing ET (met). nj indicates one or more jets above a minimum ET threshold.

In actual implementation, individual algorithms may be tied to RoIs passing specific threshold sets. For leptons and hadron RoIs, this includes minimum cluster thresholds along with isolation and/or quality criteria. For jet RoIs, this would indicate jet definitions with a given radius and minimum ET sum.

The choice of object threshold may be critical to performance. For example, a two-jet invariant mass M(jj) has little rejection of the mass cut on two jets over threshold t when applying M>T=2t, but the situation is different for T > jet thresholds. Similarly, the scalar sum HT (or Jet MET) is nearly as vulnerable to pileup as Sum ET (or MET) if the jet threshold is very low; raising the threshold trades poorer resolution for better pileup immunity.

Simple computations

The following algorithms involve 1 or 2 RoIs, possibly in quadrature. Algorithms may be performed on only the leading RoIs after sorting, or in parallel on all RoIs passing a given threshold:

- Delta phi (x,y)
- Delta eta (x,y)
- Delta R (x,y)

The following algorithms may involve n ROIs:

- Scalar transverse momentum HT (x)
  (definitions vary: either j, or also including leptons and met)
- Jet MET (nj)

More complex computations

The following algorithms can involve 3 or more RoIs:

- Invariant mass M (x,y)
- Invariant transverse mass Mt (x,MET)
- Mtc (x,MET) – This is the same as Mt, but opposite sign in cos dphi term. This cut is used in the event filter for SUSY/jets
- Vector sum Vr(x) to define phi axis, the ratio of two dot product sums/ratios.
- Sphericity, Aplanarity(nj) : Complex, involves solving a cubic

Overlap Removal

The following algorithms are aimed at removing ambiguity from objects that are identified as more than one RoI type:

- Lepton-jet overlap(l,j) removal
- Electron-tau overlap (e,tau) removal

Overlap removal means counting as the second object only those objects not already counted as the first object type, so for example a e2j trigger means an electron and two additional jets, not one electron double-counted plus an additional jet.

Conclusions

From the above lists, we can conclude that:

- Each lepton RoI will need to report a transverse energy sum, plus additional isolation and/or quality threshold information to allow optimized selection by various algorithms in L1Topo

- Jets should report ET sums for each jet size/definition needed in L1Topo.
- L1Topo will also require at least a missing transverse energy vector for some calculations. This will be provided initially by the L1Calo JEP, and later also by jFEX.

Input data contents and format

Link contents from the various L1 trigger systems are not yet fully defined, and may change over the operational life of L1Topo. The furthest-developed proposals are for the Jet and EM/tau processor subsystems in L1Calo, which we present here. From these we can make estimates of bandwidth allocation for each of the L1 trigger systems

A working assumption for all data formats is that RoIs sent to L1Topo by a given hardware module will include coordinate information that explicitly defines the location of the RoIs *within the coverage of that module*. L1Topo will remain 'aware' of the mapping of links to its inputs, and can add additional coordinate information to RoIs based on which link the RoI arrived.

In addition to coordinates, RoI data should include (as applicable):

- Transverse energy/momentum. Most RoIs will contain a single ET, but jet ROIs should report separate ET sums for different sizes/definitions.
- Isolation/quality threshold information. At higher luminosities, E/gamma, tau and possibly muon RoIs will require additional cuts based on isolation and other object qualities.

All objects satisfying the *most permissive criteria* (minimum ET threshold, loose/no isolation, etc) will be identified as RoIs and entered into the real-time data path. Once they are received in L1Topo, additional cuts and thresholds can be applied for use by different algorithms.

For the following sections, we assume a baseline link speed of 6.4 Gbit/s, corresponding to a data payload of 128 bits per bunch crossing. Higher speeds are under investigation including 10.0 Gbit/s, corresponding to a data payload of 200 bits per bunch crossing. If higher link speeds prove practical in a large, distributed system then some subsystems may be able to achieve higher bandwidth densities..

L1Calo EM/Tau CMX

For the L1Calo cluster processor subsystem, it is estimated that a EM or Tau RoI coordinates, cluster energy and isolation information can be transmitted to L1Topo in 24 bits:

- CPM position (1-14) : 4 bits
- Coarse position (to 0.2 × 0.2) of RoI in CPM : 4 bits
- Fine position (to 0.1 × 0.1) : 2 bits
- Cluster ET sum : 8 bits
- EM isolation ring threshold : 2 bits
- Hadronic isolation ring threshold : 2 bits

- Hadronic veto (for EM clusters): 2 bits

Assuming a 6.4 Gbit/s link speed with a data payload of 128 bits/bunch crossing, five such RoIs can be reported per fiber link, for a total of 120 bits. The remaining eight bits would be reserved for status information and checksums.

L1Calo Jet CMX

For the L1Calo jet processor, it will be possible to report ET sums for two different jet cluster sizes (from a menu of 0.4×0.4, 0.6×0.6, and 0.8×0.8) that pass a minimum threshold. With coordinate information included, each jet RoI would then be reported in 29 bits:

- JEM position (1-14) : 4 bits
- Coarse position (to 0.4 × 0.4) of RoI in JEM : 3 bits
- Fine position (to 0.2 × 0.2) : 2 bits
- ET sum, jet cluster size 1 : 10 bits
- ET sum, jet cluster size 2 : 10 bits

Again assuming a 6.4 Gbit/s link speed with a data payload of 128 bits/bunch crossing, four such RoIs can be reported per fiber link, for a total of 116 bits. The remaining twelve bits can be reserved for status information and checksums.

L1Calo Energy-sum CMX

It is presently uncertain what additional use can be made of the additional bandwidth between the the energy-sum FPGA on the JEM to the CMX, besides possibly transmitting uncompressed Ex, Ey and ET sums uncompressed for some minor gain in resolution.

That said, a number of potential topology algorithms make use of the missing ET vector, so each energy-sum CMX will need to send at least one fiber link to L1Topo. This give at least 128 bits per CMX, which provides room for the CMX to produce other, possibly useful energy-sum information. Potential sums sent to L1Topo may include:

- Sum ET : 15 bits
- Sum ET, first quadrant : 15 bits
- Sum ET, second quadrant : 15 bits
- Sum Ex, including sign : 16 bits
- Sum Ey, including sign : 16 bits
- Sum E (calculated geometrically from JEM ET sums) : 15 bits

Another possibility might be to transmit all data received from all JEMs to L1Topo, although it is unclear if there would be a benefit.

eFEX

The eFEX subsystem architecture has still not been fully established, but it is possible to estimate link contents and multiplicities based on a few reasonable assumptions:

From current baseline proposals for fiber count per input ribbon and PCB densities, the eFEX may fit within two ATCA crates. This gives up to 14 eFEX modules, each with a 'core' angular coverage of approximately 4 × 32 trigger towers, or twice the coverage of an L1Calo CPM.

Each eFEX module will effectively transmit results directly to L1Topo via one or more fiber links, at a link speed of at least 6.4 Gbit/s.

The current baseline for EM input data to the eFEX is the so-called '1441' scheme, with one 0.1× 0.1 sum each per trigger tower from the pre-shower and back layers, and four 0.025 × 0.1 sums each from layers 1 and 2. Hadronic data would consist of one 0.1× 0.1 sum per tower, with no layer information.

eFEX e/gamma RoIs

With the '1441' scheme, a number of different algorithm options are available in the favored 0.3 × 0.3 sliding window size. If L1Topo is allowed to apply different cuts for different topology algorithms, the eFEX e/gamma RoI information might include:

- Cluster sum ET : up to 14 bits
- R_η 'cluster-sum/environment' threshold for layer 1: 3 bits
- R_η threshold for layer 2: 3 bits
- Hadronic isolation threshold: 3 bits
- Coordinate of RoI within eFEX module (to 0.1 × 0.1) : 7 bits

With these assumptions, we arrive at a total of 30 bits per eFEX RoI, allowing up to four eFEX RoIs to be sent per 6.4 Gbit/s fiber, with 8 bits/fiber remaining for checksum and other flags. There is some margin in these numbers, especially cluster sum ET and hadronic isolation, so some adjustment is possible.

eFEX tau RoIs

The eFEX can provide sliding-window algorithms up to 0.5 × 0.5 for taus, but simulation studies have not yet produced a baseline eFEX tau algorithm. That said, a tau RoI is likely to have similar amounts and types of information as for the e/gamma format, including overall cluster ET, shower profile thresholds in different layers, isolation ring thresholds around the tau cluster, and 7-bit coordinates.

Therefore, for tau RoIs in the eFEX we can also conclude for the moment that four RoIs can reasonably fit in each 6.4 Gbit/s fiber.

jFEX

The jFEX architecture and partitioning are also not yet well understood, but based on the L1Calo jet trigger, we can make similar assumptions about jet RoIs from the jFEX.

Assume for the moment a single-crate system with eight jFEX modules and sliding windows with 0.1 × 0.1 granularity. Each jFEX would then have an approximate angular coverage of 64 × 8 trigger towers. RoIs in such a module would then need to be reported with 9 coordinate bits.

Assuming also that we might want to report jet ET sums for 'narrow' and 'wide' jets, the contents of a jFEX jet RoI might include:

- Jet sum ET (wide): 11 bits
- Jet sum ET (narrow): 10 bits
- Coordinate of RoI within jFEX module (to 0.1 × 0.1) : 9 bits

This scheme would result in 30 bits per jet RoI, allowing four such RoIs per 6.4 Gbit/s fiber with eight additional bits for flags and checksums.

It should be noted that the jFEX will also be responsible for providing transverse and missing transverse energy sums to L1Topo. If the ET, Ex and Ey sums from each jFEX module can be encoded in 10 bits, then these can also be transmitted to L1Calo, at the cost of one fewer RoI per jFEX module.

L1Muon

Current assumptions about the MUCTPI upgrade point towards a system with four modules, each processing four octants in L1Muon. If coordinates to 0.1 × 0.1 are desired, then 10 coordinate bits are necessary to designate the position of a muon RoI in the MUCTPI module's angular coverage.

The contents of a muon RoI might then include:

- Muon momentum : Three (3) threshold bits
- Charge sign from TGC: 1 bit
- Flag bits for NSW coincidence: 2 bits
- Coordinate of RoI within module (to 0.1 × 0.1) : 10 bits

This gives 16 bits per muon RoI. Leaving some space for additional flags and checksums gives up to 6-7 RoIs per 6.4 Gbit/s fiber.

Link allocation to L1Topo

To minimize latency, it is not foreseen to sort the RoIs before transmission to L1Topo. That means it is important to have generous bandwidth margins at all stages of the real time data path, so that truncation will only occur in rare, pathological cases. For such events it will always be possible to detect this truncation, accept the event, and read out the full, untruncated list of RoIs to the HLT.

Based on the assumptions in the previous section, we can estimate the fiber link budget for the L1Topo inputs in Phase 1. The table below represents an example of such a budget. An optical fiber splitting and re-bundling stage is assumed to optimally pack the available RoIs into the available 12-channel parallel optic receivers. Since each module is expected to require only part of a 12-fiber bundle to send its ROIs, it will be possible to send duplicate sets of RoI data in parallel to multiple L1Topo modules.

Assuming 6.4 Gbit/s links from all subsystems, a link budget could be organized as follows:

RoI source	**Modules**	**RoIs/ fiber**	**Fibers/ module**	**Max # RoIs/ Module**	**Total # Fibers**	**Max total RoIs**
CMX e/γ	4	5	4	20	16	80
CMX τ	4	5	4	20	16	80
CMX jet	2	4	6	24	12	48
CMX ΣE	2	*	1	*	2	*
eFEX e/γ	14	4	2	8	28	112
eFEX τ	14	4	2	8	28	112
jFEX	8	4	3	11**	24	88**
MUCTPI	4	6	4	24	24	96
				Total number of fibers to L1Topo:	150 (of 160 available)	

Notes:

* The ΣE CMX does not report RoIs, only transverse and vector energy sums

** Each jFEX module also reports 30 bits of tranverse and vector energy sums