Estimation of Phase-1 Topological Trigger Requirements

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METHODOLOGY

Using the expected Phase-1 FEX output numerology, and the CTP input constraints, a strawman Phase-1 topological trigger connectivity is proposed, on the basis of three Phase-1 Topological Trigger modules. Initially the strawman model is designed around the i/o capability of the legacy topological trigger, in order to understand any limitations implied by the current design at Phase-1. This is then adapted for a potential new design with higher i/o capabilities. A preliminary estimate of the usage of CTP inputs is also provided, with some considerations of phasing in items during the initial commissioning phase of Run 3.

TRIGGER REQUIREMENTS

Predicting the Trigger Menu for Run-3 is necessarily an imprecise procedure, but guidance from the current usage of Topological and non-Topological items can be used as a reasonable starting point. There is plenty of experience of the usage of non-Topological trigger items, so estimates based on current (2016,2017) menus are likely to be quite close to reality for most of the basic EM, MU, TAU, Jet and Missing Energy triggers. In general, it is assumed that a Run-3 menu will place roughly the same requirements on these in terms of non-Topological triggers. The only area in which this assumption cannot be applied directly is for triggers based on the new global jet processor (gFEX). The estimates in this note assume that the requirements here will be approximately the same as the standard jet items, so the total number of jet items is effectively doubled. This is probably an over-estimate, but at least in the initial stages of Run-3, all items will be studied for performance improvements, and only later can the number of items be cut down to those that prove to be most effective.

For topological triggers, again the same assumption is made that the Run-3 items are likely to be similar to the current items, both in terms of number required and the type of objects combined. Here the estimate is likely to prove less accurate. With more experience of the working Topological trigger in Run-2, it may well prove that some of the current items are not as useful as others, or form unnecessary duplication, and also new items may be introduced. It seems likely that when fully understood, many of the similar 'near-duplicate' items in the Topological Menu will be honed down to a smaller number of the most useful items. So in terms of numbers, again the current usage may well be an over-estimate of the ultimate requirement, but it is still a reasonable guideline, and certainly important in informing the need for combining objects of different types.

TOPO INPUTS FROM PHASE-1 FEXES AND MUCTPI

This section will summarize the expected numerology of inputs to the Topological trigger, with some rough details of the type of information transmitted. The details here are preliminary and may change, but they constitute the best knowledge at this point of time.

eFEX

There are 24 eFEXs which produce both EM and Tau objects. The plan is to send EM and Tau TOBs on separate links, each type using two fibres. The TOBs will be prioritized such that the most significant TOBs (distinguished by a combination of high transverse energy and isolation) will be sent on the 'high-priority' fibre, before other, lower energy TOBs, are sent on the remaining slots on that fibre, and the second fibre, if required. It is expected that 7 TOBs can be sent per fibre, and up to 8 copies of each fibre can be provided, which is more than enough for three Topological modules. Recent ideas suggest a full sorting mechanism, rather than prioritization, will be possible in the eFEX, which means the TOBs on the second fibre are even less likely to be significant.

jFEX

There are 6 jFEXs which produce Jet objects and Missing Energy information. The four FPGAs per board all produce jet TOBs which are expected to be sent out on two fibres per FPGA, with a probable count of 6 TOBs per fibre. There is currently no plan to sort these jet TOBs in the jFEX, but they will be packed onto the first fibre, unless that is not sufficient, in which case the rest will appear on the second fibre. Two of the FPGAs also produce Missing (and Total) Energy information, so the total output of one jFEX is contained in 10 fibres, 8 for jet information, and 2 for energy. Because some FPGAs require 3 fibre outputs, and each has a limit of 12 fibres, simple duplication means that only four copies of the full information will be available to Topo.

gFEX

There is one gFEX producing complimentary Jet objects and energy information using larger jet areas and global quantities. There are several varieties of jets (including fat jets and substructure measurements) and also several algorithms for Missing and Total energy making use of the global scope of the gFEX module. It is planned to send the global information on 2 fibres, and the jet information on 6 fibres. In both cases this corresponds to 2 links per FPGA out of a total of 12 fibres available, meaning that 6 identical copies of the gFEX information can be provided to Topo. For the purposes of counting fibres later in this note, the gFEX fibres will be considered as a bundle of 8, though if it deemed necessary, the energy and jet information could be provided separately.

MUCTPI

The upgraded Phase-1 MUCTPI will send more detailed Muon TOBs than those currently available. It will also perform some Muon-only topological algorithms to be sent directly to the CTP. The full output to Topo is expected to take 8 fibres, and many copies (at least 6) are available. It will not be necessary for the Topological trigger processor to form simple threshold multiplicities of Muon TOBs, since they will be sent directly to the CTP from the new MUCTPI. The MUCTPI will also form all Topological items consisting purely of Muon TOBs.

SUMMARY OF TOPO INPUTS

The table below summarizes the type and multiplicity of inputs to the Topological Processor. For ease of reference later in the document, shorthand names are given in the final column.

TOB type	Fibres	Copies	Name
Muon TOBs	8	6	MU
EM TOBs (high priority)	24	8	EM1
EM TOBs (low priority)	24	8	EM2
Tau TOBs (high priority)	24	8	TAU1
Tau TOBs (low priority)	24	8	TAU2
Jet TOBs (first fibre)	24	4	JET1
Jet TOBs (second fibre)	24	4	JET2
jFEX Missing/Total Energy	12	4	XE
gFEX jet TOBs and global quantities	8	6	GFEX

Note that in each case, the number of fibres is a multiple of four. This means that, for a Topo FPGA taking all inputs of a certain type, the input fibre numbers all match nicely to the quad transceiver structure which is typical of the FPGA link inputs and outputs. There should be no need to mix inputs of a different type in the same input quad, hence no issues with differing clock speeds.

TOPO OUTPUTS TO CTP

Topo decisions can be sent to the CTP by one of two routes, electrical or optical. The electrical route has the advantage of lower latency (probably three BCs faster), so should be reserved for algorithms that are likely to be on the critical latency path. The CTP can receive up to three electrical cables with a capacity of 64 decision bits per cable. The optical fibre route has a higher bandwidth, with up to 12 possible inputs and 128 bits per fibre. One of the CTP input fibres will be used by the direct MUCTPI inputs, but there is no shortage of supply for Topo inputs. There is also unlikely to be any restriction on the number of output fibres per Topo – for example, one per FPGA on the Topo module should easily cover all trigger items produced by each FPGA. The only likely restriction is on the usage of electrical Topo outputs for signals that need to be transmitted by the fastest route.

NON-TOPOLOGICAL TRIGGER ITEMS

In this section, the requirements for simple thresholding and multiplicity triggers will be studied. These are assumed to be simple (and fast) algorithms based purely on a single type of TOB input, and will replace the functionality of the CMX in the legacy Run-2 system, with some enhancement related to the new global processor. These triggers can be thought of as 'non-topological' even though they will be formed by algorithms in the Topological processor.

The 2016 trigger menu was studied to understand the actual usage of the multiplicity triggers, in order to estimate the probable quantity of bits required for the Run-3 menu. Allowing for a small expansion, this seems a justifiable approximation, as the increased luminosity will mostly affect the value of the thresholds, not the number of trigger items needed.

The table below summarizes the 2016 trigger menu requirements and estimates the Run-3 requirements in terms of the number of bits to be transmitted to the CTP (rather than the number of algorithms – a multiplicity trigger up to a count of seven presumably only requires one algorithm, but produces three output bits). Note that the number of bits used in 2016 is far smaller than the number actually provided by the CMX modules (and MUCTPI), as many of the high multiplicity options (up to 7 in some cases) are never needed in a real physics menu.

Type	**Bits used in 2016**	**Bit requirement for Run-3**
Muon	13	16
EM	24	32
Tau	10	16
Missing/Sum Energy	8/8	16+
Jet	40	48
gFex jet + energy + global		48

The numbers here are very approximate, but can be seen to fit easily into two optical fibres, and given that these algorithms should be simple, the longer optical path should be fine. It should be noted that the numbers for the gFex triggers is very approximate, purely based on the current Jet requirement. Also the number of Sum Energy triggers, though excessive for proton physics, is potentially rather limited for Heavy Ions. Either more bits and algorithms should be assigned here, or perhaps some flexibility should be built in to perform a different set of algorithms and re-assign output bits for Heavy Ions data periods, but these do not have to be performed in the Topo module assigned to non-topological triggers.

TOPOLOGICAL TRIGGER ITEMS

The potential requirements for Topological trigger items can also be estimated from the Topological trigger menu in 2016. Although this area is likely to see more development during the rest of Run-2 and before Run-3, it should still prove useful as an indication of the useful mixture of TOB types required in typical topological triggers. Again some method of coping with the new global jet triggers must be considered. Any topological trigger that currently uses the standard jets or missing energy might benefit in Run-3 from using gFEX-based TOBs and quantities. This could result in quite a large increase in candidate topological triggers, at least in the early phase of Run-3, before it is established which algorithms have the best performance. The high-bandwidth optical fibres should be able to handle this, though there might be more of an issue with competition for electrical transmission for slower algorithms. The limited total number of CTP inputs may also become an issue, so provision should be made to prioritize the most important triggers initially, while other potential algorithms can be monitored for performance.

A simplified summary of the topological triggers defined for the 2016 menu is given below. Approximately 140 items were specified, though only about 100 of these were implemented in the 2016 topological module firmware. Note that, as with the simple multiplicity triggers, many of these are similar and several versions are defined for flexibility of switching. Once the performance is analyzed, it is likely that the number of actual algorithms and bits needed will reduce to those that prove to be most effective. The table gives the number of topological algorithms based on the types of TOB inputs required, and also a brief (and incomplete) indication of the physics area where these are useful.

TOB types	Approximate number of Algorithms	Physics Case	Location
MU only	40	B Physics and S.M. J/psi	MUCTPI
EM only	8	J/psi electron	TOPO 2
Jet only	15*	SUSY, Exotics (MJJ)	TOPO 2
MU + XE	4*	Exotics (Late)	TOPO 2
MU + EM	5	Exotics (LFV)	TOPO 2
MU + Jet	7*	B-tag	TOPO 2
Jet + XE	25*	Higgs, SUSY (KF)	TOPO 2
MU + Jet + Tau	3*	Higgs (Disambiguation)	TOPO 3
EM + Jet + Tau	3*	Higgs (Disambiguation)	TOPO 3
XE + Jet + Tau	6*	Higgs (Disambiguation)	TOPO 3
XE + Jet + EM	15*	J/psi, W tag/probe	TOPO 3
EM + Tau	8	Exotics (LLP)	TOPO 3
	* plus more using gFex		

The final column gives the distribution of the algorithms over the topological modules, which will be detailed in the next section. Note that although the number of algorithms is likely to increase in Run 3, the burden is already partly off-loaded onto the MUCTPI and there will be more topological modules available than currently in Run-2. A consequence of this is that the numbers of algorithms (and bits to be sent to the CTP) does not look problematical, at least if all were to be sent optically. However, the restriction on fast electrical signals may still limit these numbers for slow algorithms.

STRAWMAN TOPOLOGICAL CONNECTIVITY

Having covered the input, algorithm and output requirements, it is now possible to create a potential model for the distribution of algorithms between topological modules, and enumerate the input and output links. Numbering the three Phase-1 Topological processors as TOPO1-3, the overall scheme for the assignment is given below. Note the number of algorithms/bits to CTP, based on the previous arguments, is given in brackets:

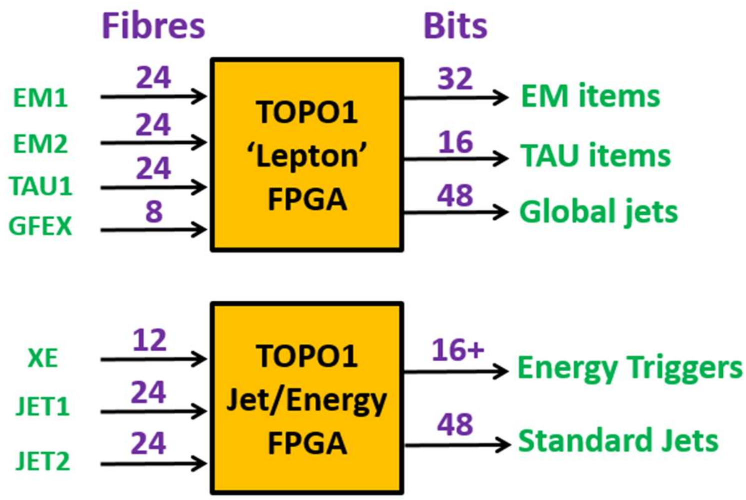
- MUCTPI: Muon multiplicities and pure Muon topological algorithms (16+40)
- TOPO1: All other multiplicity triggers including gFEX items requiring no processing (160+)
- TOPO2: Topological algorithms requiring 1 or 2 TOB types (~65)

- TOPO3: Topological algorithms requiring more than 2 TOB types (~35)

It is assumed that the Topological Processor will consist of two FPGAs which can work independently, but there is potential for signal forwarding from one FPGA to the other, at the cost of some latency. In the case of TOPO1 it is clear that no FPGA to FPGA links will be needed to perform the thresholding, so both FPGAs can run independently with separate (fibre) outputs to CTP. It would also be desirable to run TOPO2 in the same way, which is why it is limited to algorithms which combine a small number of TOB types. It will be seen that with the current FEX output fibre counts, Run-2 Topoological Processor and the complexity of the algorithms in TOPO3, it is likely that the FPGA to FPGA links will be required for some trigger items.

Connectivity of Topo1

There is some freedom to rearrange inputs and outputs in the simple thresholding/multiplicity Topo, but a reasonable setup is shown in the diagram below.

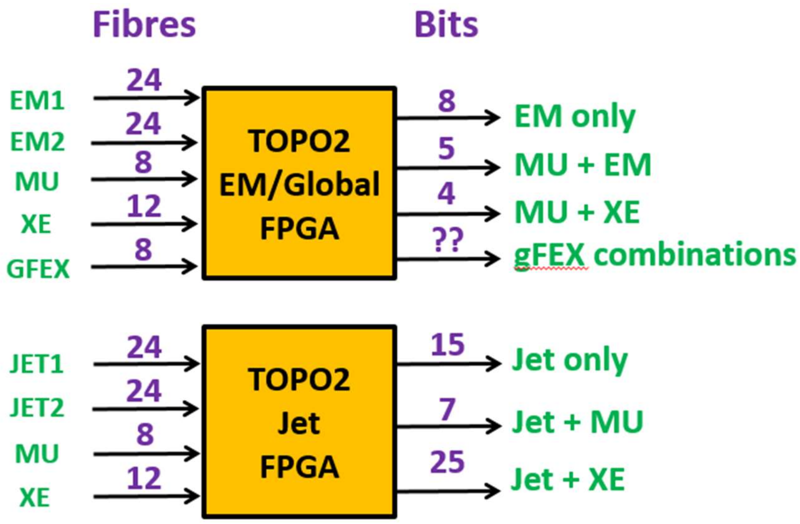


Each of the FPGAs requires one fibre output to the CTP, assuming that these algorithms are fast. The bandwidth on the fibres allows for the estimated usage with some extra capacity. The choice of placing the gFEX algorithms on the 'Lepton' FPGA means that more output bits are available, since the jet items require more output decision bits, so combining gFEX and jFEX inputs onto one FPGA, though possible in terms of input fibres, might restrict the number of trigger items which can be sent to the CTP on one fibre.

Connectivity of Topo2

The algorithms on this module cope with most of the simpler topological algorithms which require a small number of different TOB types. Note that the TAU inputs do not appear in this module at all. The connectivity is shown in the diagram below.

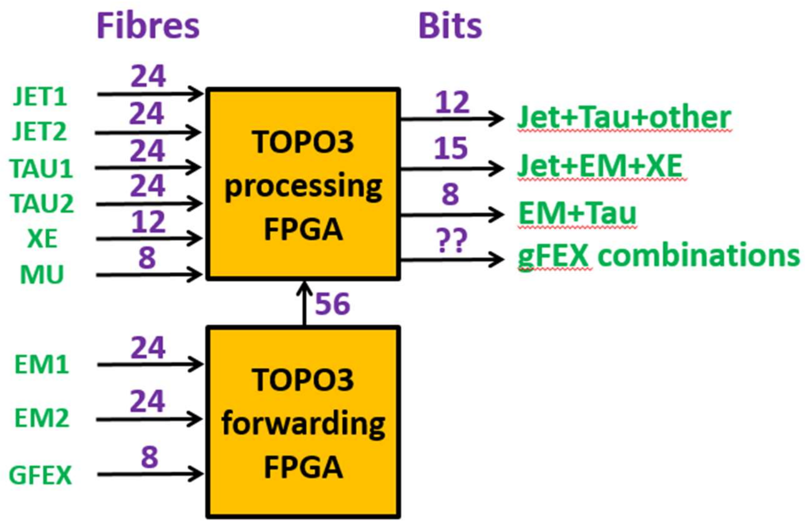
As with TOPO1, there is no requirement for interconnection between the two FPGAs. The outputs can easily be accommodated by one fibre per FPGA, even allowing for the fact that the numbers given are purely based on current usage, so may change considerably. There is also plenty of capacity for new algorithms based on combinations of gFEX inputs with other TOBs (particularly EM and MU) which would form the gFEX equivalent of some of the current Jet combined triggers.



One additional consideration for this module is that some of the algorithms may be slow. So while all outputs could still be routed to the fibres, it may be necessary to route some algorithm results to an electrical cable to be transmitted more rapidly to the CTP. So this module should be assigned two fibre outputs plus an additional electrical cable.

CONNECTIVITY OF TOPO3

This module contains all the most complex algorithms, and so requires the highest connectivity, as shown in the diagram below.



This illustrates that to implement some of the most complex algorithms, while also requiring all inputs from systems such as eFEX and jFEX, results in a very demanding input count into one FPGA. Other arrangements are possible which may spread this load, in particular by redistributing the algorithms between TOPO2 and TOPO3. However, an algorithm that requires all EM, Tau and Jet TOBs will inevitably need to have 144 inputs, and will be difficult to accommodate in any layout.

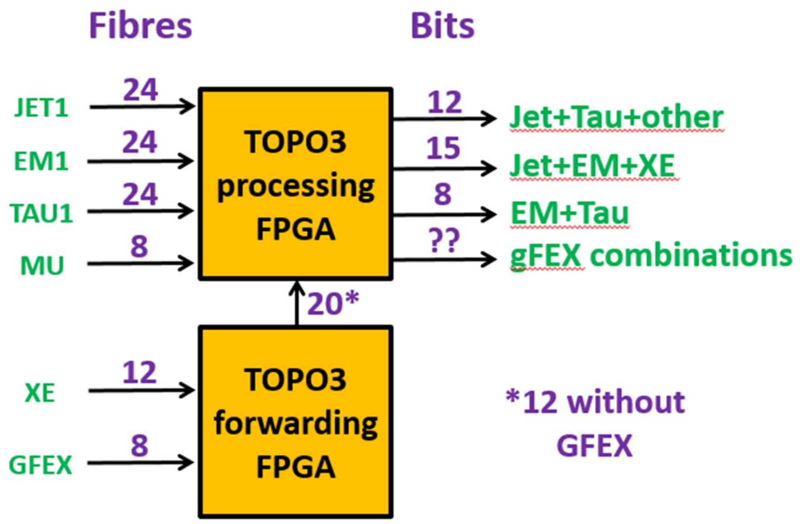
Other than the high connectivity, in other ways the arrangement of this module is simple, with one FPGA purely forwarding data to the other. Depending on the algorithms, it may be possible to perform some pre-processing of the forwarded information in order to reduce the FPGA-FPGA bandwidth required. A different division of input signals may help with this task – for example, the EM and TAU inputs could all be routed to the forwarding FPGA, and on most events, these will contain a relatively small number of TOBs, so could be compressed onto a few links.

For output to CTP, only one link is required. A fibre could be provided as a fall-back solution, but undoubtedly, the algorithms on this module will require a fast electrical link to the CTP.

CURRENT TOPOLOGICAL TRIGGER SPECIFICATION

In the current Topological trigger, the main limitation relevant to this study is the number of optical fibre inputs per FPGA, which can be up to a maximum of 80 links. This means that in terms of connectivity, at least, the current module would be suitable for TOPO1 and TOPO2 in the above strawman model. However, it would not be able to provide the full functionality needed for TOPO3, so some algorithms could not be performed in the exhaustive version described above. This note does not address the internal resources required to perform the range of algorithms, but it may also be that the current FPGAs are not powerful enough for the more demanding load coming from the Phase-1 FEXes.

It is possible to conceive of a reduced version of TOPO3 to illustrate the compromises needed to use the current module in Phase-1, as shown below:



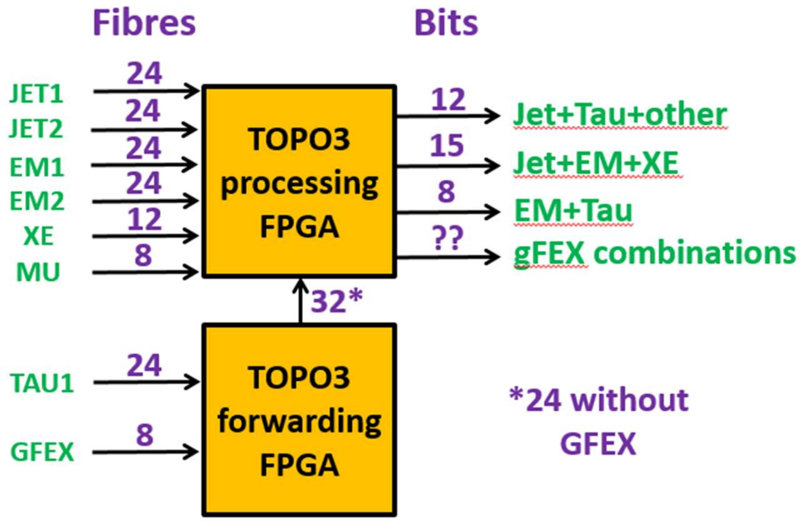
The main reason why input becomes critical in the strawman arrangement is the large number of EM, TAU and Jet fibres. The original concept of low/high priority TOBs on the EM and TAU links has recently been superseded by the expectation that there will be a full sorting algorithm taking place in the eFEX. It will hopefully be guaranteed that the top 7 TOBs will appear on the first fibre. Moreover, it is likely that on most events, the second fibre will contain no TOBs, as they will all fit onto the first fibre. Studies have shown that the rate of overflows are small, and provided that these overflows are flagged, the second fibre can be omitted. Note that this is particularly true for TAU TOBs – indications from the current system are that multiplicities likely to cause overflow of Tau TOBs at the thresholds deemed useful for physics are essentially non-existent. So in the revised version, we omit EM2 and TAU2, which reduces the necessary FPGA to FPGA connectivity to a more reasonable level.

This design may fit into the current Topological processor with or without the need for preprocessing the inputs to the forwarding FPGA. However, it is still necessary to use the FPGA forwarding route to perform all algorithms, which inevitably brings with it a latency penalty.

Extension to Enhanced Topological Trigger Modules

If the specification of the Topological trigger were to be enhanced for Phase-1, then accommodating the needs of TOPO3 becomes easier, though not trivial. The proposed upgraded Topological module will have the capability to receive 118 fibres directly into each FPGA, rather than 80 in the original module. With the strawman model, again the demands of TOPO1 and TOPO2 on connectivity should not be a problem, but an updated FPGA will be able to provide more resources. Also, it would be possible to add more inputs, if needed, to those already defined. For example, TOPO1 could also receive the 24 TAU2 fibres, so that there would be less need to worry about overflows in the TAU path.

However, even with an upgraded module, the i/o demands of TOPO3 look difficult for algorithms which expect all Jet, EM and TAU TOBs . A possible solution is shown below.



The general layout is similar, and there is still a need for inter-FPGA communication, but with fewer links even without preprocessing (24 links if gFEX combinations are not required). The output routing is still likely to require the fast electrical cable.

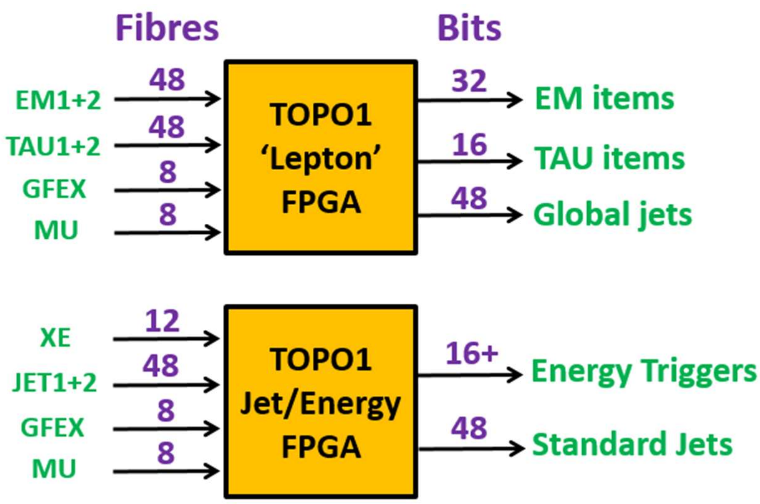
The saving made here is to drop the requirement on the second TAU fibre. As stated above, current running conditions suggest that with a reasonable lowest tau threshold, it is highly unlikely many TOBs will be sent on this second fibre. Additionally, in the current Topo, many of these algorithms work on an abbreviated list anyway, so the sorted TOBs on the first fibre may be sufficient. On the other hand, it is more likely the second fibre will be needed for Jet triggers. For jets, this is particularly true in the FCAL region. For EM TOBs, if there is still a need for J/psi triggers, the threshold will have to remain very low, and the second fibre could still be useful. However, electron J/psi triggers are not a driving physics motivation, and some compromise may be acceptable here. Dropping the second EM fibre for these, and a few other algorithms, makes another solution possible, as described in the next section.

Alternative using Enhanced Topological Trigger Modules

The latency envelope for Phase-1 is very tight, and so it would be preferable if there were no need for FPGA-FPGA forwarding. The topological items that drive the need for forwarding are the Higgs disambiguation triggers, using Jet+EM+Tau, and also the W to electron (missing energy tag and probe) which requires Jet+EM+XE. With some rearrangement, the second of these can be dealt with satisfactorily. In the case of the Higgs disambiguation, if the needs are relaxed slightly, namely to require only one fibre for EM and/or Tau, then data forwarding can be avoided entirely using the following scheme.

Connectivity of Topo1

TOPO1 should be maintained (at least initially) as the location for simple threshold triggers for ease of commissioning. However, given the larger input capability of the new module design, all inputs can be accommodated, including the Muons. Also a gFEX input can be provided to both FPGAs. This means that there is a later possibility to add gFEX jet based topological algorithms, combined with all other objects, if it is found that these can offer an improved performance over jFEX based jet algorithms.



Algorithm Partition

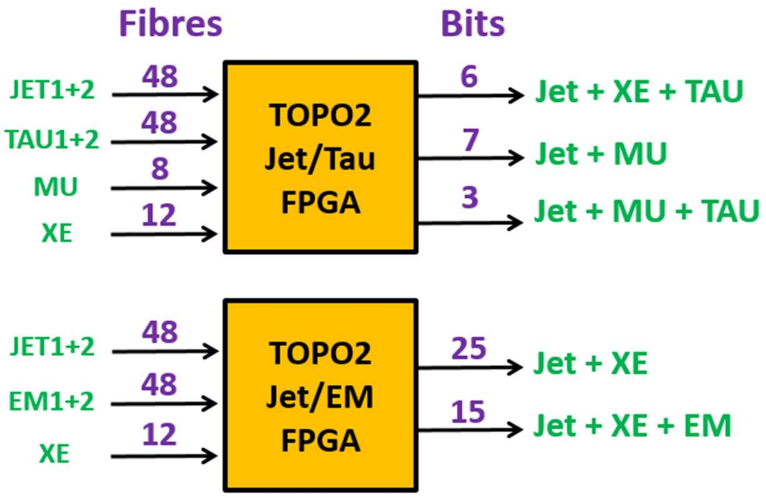
The topological algorithms will need to be assigned in a different way to topological modules to accommodate the new scheme. The partitioning is shown in the table below.

Note that emphasis has been put on providing every possible way of combining Jet and Tau objects, since this appears to be one of the key areas where topological triggers can contribute to the ATLAS physics programme.

TOB types	Approximate number of Algorithms	Physics Case	Location
MU only	40	B Physics and S.M. J/psi	MUCTPI
Jet + XE + Tau	6*	Higgs (Disambiguation)	TOPO 2a
Jet + MU	7*	B-tag	TOPO 2a
Jet + MU + Tau	3*	Higgs (Disambiguation)	TOPO 2a
Jet + XE	25*	Higgs, SUSY (KF)	TOPO 2b
Jet + XE + EM	15*	J/psi, W tag/probe	TOPO 2b
Jet only	15*	SUSY, Exotics (MJJ)	TOPO 3a
EM + Jet + Tau	3*	Higgs (Disambiguation)	TOPO 3a
EM only	8	J/psi electron	TOPO 3b
EM + MU	5	Exotics (LFV)	TOPO 3b
EM + Tau	8	Exotics (LLP)	TOPO 3b
MU + XE	4*	Exotics (Late)	TOPO 3b
	* gFex combinations in	TOPO1	

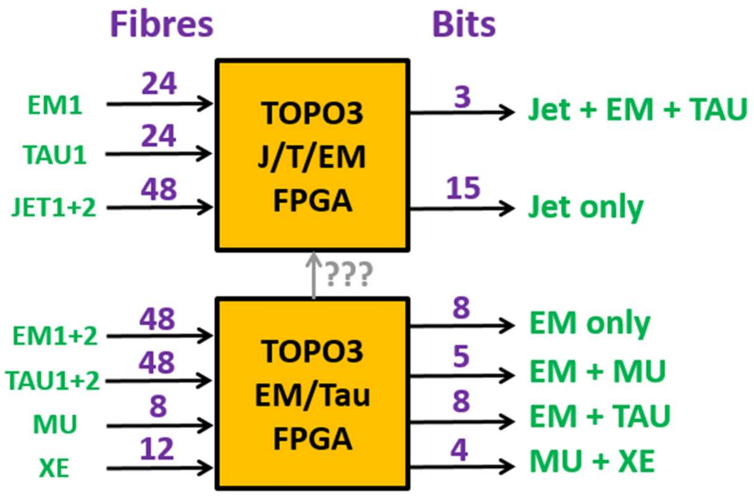
Connectivity of Topo2

As the table above shows, TOPO2 is dedicated to comprehensive combinations of Jet and Tau, and Jet and EM objects, along with Muons and Missing energy where appropriate. This is, in many ways, the heart of the Topological programme in trying to make better use of the TOB information to pick out the more interesting standard model events from the bulk QCD data. There is no restriction on the quantity of Jet, Tau or EM TOBs available, beyond that of the output bandwidth of the FEX modules, but a full Jet/Tau/EM combination is impossible in this module.



Connectivity of Topo3

TOPO3 is largely dedicated to topological triggers typically involving electrons, ranging from the standard model performance triggers, to exotics triggers involving many lepton flavours. The connectivity is shown below.



The top Jet/Tau/EM FPGA is where the bandwidth critical Jet+EM+Tau algorithms are located. These are the ones, that, in principle, may require the second EM and/or TAU fibre, but if one fibre is adequate, then the algorithms only need the direct connections of that FPGA. On the other hand, if it is found at a later date that more information is required from EM2 or TAU2, there is the possibility of forwarding this information from the second FPGA. It is hoped that this will not be necessary, as this will also introduce additional latency. Further experience of topological algorithms in Run 2, and Phase-1 upgrade performance in Run 3 should clarify this situation.

Summary of FEX and CTP connectivity

The maximal requirement for input and output fibres and cables is summarized in the table below for the strawman model.

		CTP	**TOPO1**	**TOPO1**	**TOPO2**	**TOPO2**	**TOPO3**	**TOPO3**	**TOTAL**
	Fibres		FPGA 1	FPGA 2	FPGA 1	FPGA 2	FPGA 1	FPGA 2	**COPIES**
MUCTPI	8x	1			1	1	1		4
eFEX EM1	24x		1		1			1	3
eFEX EM2	24x		1		1			1	3
eFEX TAU1	24x		1				1		2
eFEX TAU2	24x		(1)				1		1 (2)
jFEX JET1	24x			1		1	1		3
jFEX JET2	24x			1		1	1		3
jFEX XE	12x			1	1	1	1		4
gFEX	8x		1		1			1	3
			80, 104	60	76	68	116	56	

Details will vary according to the scheme chosen, and the algorithm assignments above are not the only possible arrangement. However, the most important point to be taken from this table is that there are sufficient copies of FEX outputs to feed the proposed three Topological modules in the strawman model.

There are six fibre inputs required to the CTP, 1 for the MUCTPI, 1 for TOPO3 and 2 for each of TOPO1 and TOPO2. Also two electrical cables to the CTP are required for high latency outputs of TOPO2 and TOPO3.

For the alternative scheme using the expanded topological modules, the connectivity is greater, but still within the limits of the FEX modules:

		CTP	**TOPO1**	**TOPO1**	**TOPO2**	**TOPO2**	**TOPO3**	**TOPO3**	**TOTAL**
	Fibres		FPGA 1	FPGA 2	FPGA 1	FPGA 2	FPGA 1	FPGA 2	**COPIES**
MUCTPI	8x	1	1	1	1			1	5
eFEX EM1	24x		1			1	1	1	4
eFEX EM2	24x		1			1		1	3
eFEX TAU1	24x		1		1		1	1	4
eFEX TAU2	24x		1		1			1	3
jFEX JET1	24x			1	1	1	1		4
jFEX JET2	24x			1	1	1	1		4
jFEX XE	12x			1	1	1		1	4
gFEX	8x		1	1					2
			112	76	116	108	96	116	

With each FPGA operating independently, this scheme requires 7 fibres to the CTP (one for each Topo FPGA and one for the MUCTPI). It would also be wise to connect TOPO2 and TOPO3 by the faster electrical route to CTP. Note that the MUCTPI is also expected to have 1 electrical cable to the CTP for its topological outputs.

Usage of CTP Input Routes

With the commissioning of new Level-1 items in Run 3, and new routes for those items to reach the CTP, there will have to be some flexibility in the early parts of Run 3 to accommodate and verify the correct operation of the new triggers. However, LHC may start providing challenging luminosity conditions quite soon after LS2, and so there must be a strategy for moving from old, trusted, trigger items, to the newly commissioned items without compromising the physics outcomes. In the case of the new MUCTPI, it is expected that the new system will be ready and tested for use immediately on data resumption. However, the Phase-1 calorimeter trigger is a substantial upgrade, which may require considerable time before it can be used reliably. Even if the hardware itself is fully tested before first colliding beam, there will be many timing and calibration parameters to determine before the performance of the new system can match the behaviour of the legacy system which has been debugged and tuned over the course of more than 10 years.

For reasons of stability, it is desirable that there are few changes of mode as triggers are validated. In particular, the underlying CTP connectivity should not be changed too often. Three major phases of commissioning can be defined, by thinking about which new triggers are likely to be available as time proceeds. These are:

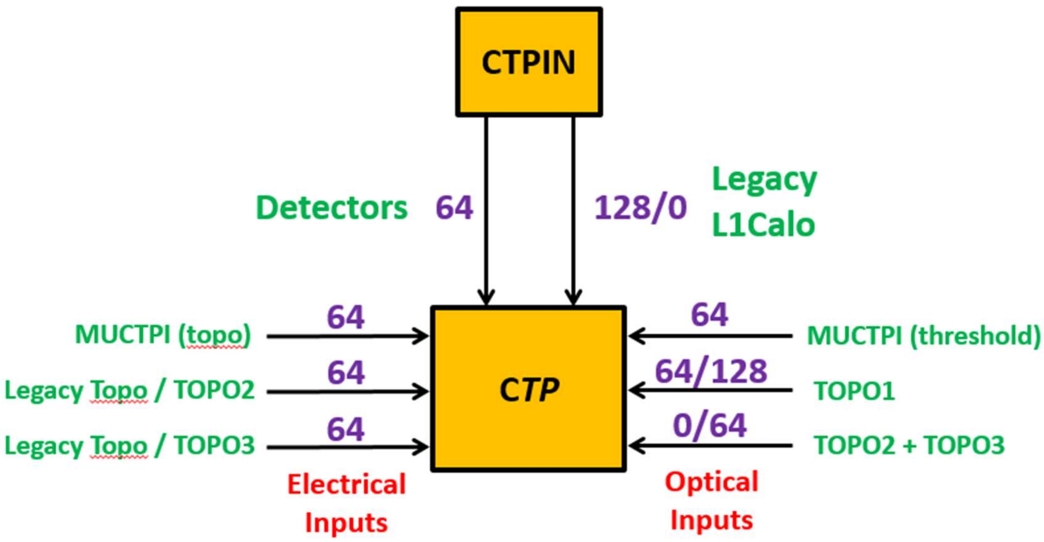
- Initial: New MUCTPI, legacy L1Calo, legacy L1Topo
- Intermediate: New MUCTPI, Phase-1 L1Calo via TOPO1, legacy L1Topo
- Final: New MUCTPI, Phase-1 L1Calo and L1Topo

This assumes that the legacy L1Calo (and L1Topo) will be necessary for first beam, and that it will be easier to commission the new simple threshold triggers (via TOPO1), before the new topological algorithms can be tuned to the Phase-1 TOBs. The ultimate goal of using all new MUCTPI and Phase-1 L1Calo and L1Topo is clear.

Note that along with the new Level-1 Muon and Calo triggers, there are several detector specific items which will still use the old route into the CTP via CTPIN modules (as will the legacy L1Calo items). In the 2016 trigger menu, there are about 90 of these items, but in the initial Run 3 menu, it might be good to reduce this to (say) 64 items since there will be some competition for CTP input bandwidth with the new items running alongside the legacy items. The detector specific items currently involve many detectors: AFP, ALFA, BCM, LHCF, LUCID, MBTS, TILE, TRT, and ZDC.

Other than the CTPIN route, Level-1 items arrive at the CTP by two other paths. These are up to 12 optical links with up to 128 bits per link, and three electrical cables with up to 64 bits per cable. As already pointed out above, the electrical links offer a lower latency path, and so should be reserved for the slower topological algorithms. The total number of CTP input items that can be defined in one trigger menu is 512, so some initial allocation of these items to the various input routes is useful as a guideline for early Run 3 trigger menus and CTP configuration.

A possible connectivity scheme during commissioning is shown below:



The three stages are shown in the one diagram. The only cabling that has to change is that between the Intermediate and Final stage, where the legacy L1Topo outputs are disconnected from the CTP, and the new Phase-1 Topo outputs (from TOPO2 and TOPO3) are connected. Up to that point, (non-muon) topological triggering still relies on the legacy system. All other changes require no physical alterations, just a reallocation of inputs into the CTP. The seven fibres from MUCTPI and the 6 L1Topo FPGAs can be connected up from the start, even if some are not used immediately.

In the Initial stage, there are 64 detector Level-1 inputs routed via the CTPIN boards, and this does not change throughout the commissioning. However, another 128 legacy L1Calo inputs via CTP are also needed at this stage. Along with the 192 topological inputs (MUCTPI and legacy Topo), there are only 128 inputs left from the optical links. 64 of these should be assigned to the MUCTPI outputs, leaving 64 for TOPO1. These are not active triggering items at this stage, but these would be vital for timing and validating the new trigger items.

Once the Phase-1 FEXes and TOPO1 triggers have been verified to be working, then the system could be moved to the intermediate stage. This disables the legacy L1Calo items, and assigns the extra bandwidth for 128 TOPO inputs to replace them. Also 64 bits are assigned to commission the fibre outputs of TOPO2 and TOPO3. Note that the MUCTPI inputs (either thresholds or topological) do not have to change at any point.

Finally, once the new topological items are commissioned, the legacy L1Topo cables can be replaced by the new L1Topo cables. The exact allocation of bits to each input route should be determined when the trigger menus are better understood, but the guideline figures given in these diagrams are a reasonable first guess which allows for commissioning to take place in parallel with the utilization of known and trusted physics items. In practice, the menu is likely to require care and streamlining to make sure all constraints are met.

CONCLUSIONS

A strawman model for Topological processor connectivity in Run-3 has been presented. This is shown to be consistent with the current expectations for FEX and MUCTPI output, and also CTP input. A suggested assignment of algorithms to Topo modules has been discussed, and in the case of two of the three modules, there are no connectivity problems even using the current design of Topological module. However, in the case of the most complex algorithms, which were assigned to the third module in the strawman model, there are quite severe input constraints. Moving to an enhanced Topological Processor with a larger input bandwidth solves most of these problems, but still requires FPGA-FPGA links for some algorithms, bringing with it a latency hit.

A second model for algorithm assignment has been proposed specifically for the enhanced topological module. In this case, it is possible to perform most of the algorithms on the full set of TOBs without data forwarding, and only a very small number of algorithms would have to work on a reduced set of EM and Tau inputs making them potentially susceptible to occurrences of TOB overflows. How much of a problem this is for the affected topological algorithms is not clear, and should have be studied, but with full eFEX TOB sorting, it seems likely that this is a minor issue. It appears the compromises required in this case are less worrying than with the strawman design. If it is found that the extra connectivity is required, there is still the possibility to do this via data forwarding, but this is not a desirable solution due to latency.

Some of the issues concerning CTP connectivity during the Run-3 commissioning period have also been addressed, and a potential scenario for moving from legacy to Phase-1 trigger items suggested. This is rather speculative at this stage, and will have to be specified more precisely when the trigger menus for Run-3 become more definitive.