D0 Upgrade *Electronics*

Generation of L1 Trigger Terms by the CFT
CFTTM Design
Version 5

by Fred Borcherding

1. Requested Information

A proposal for the information content of the L1 trigger terms from the CFT and CPS was made on May 21, 1997 by the level 1 trigger management. The request was for:

Number of CFT tracks above threshold
Number of CFT tracks above threshold with corresponding CPS hit
Number of isolated CFT tracks above threshold
Number of isolated CFT tracks above threshold with corresponding CPS hit

Where each of the above is for four Pt thresholds giving a total of 16 trigger terms.

The meaning of 'isolated' was not specifically defined. We will define it as:

A track is <u>isolated</u> if it is the ONLY track found within a CFT trigger sector AND there are NO CFT tracks found in either of the nearest two neighbor sectors.

To be isolated therefore a track must be the only one found within the middle sector of any group of five sectors. There are 80 sectors and each subtends 4.5 degrees. The meaning of 'corresponding CPS hit' also was not specifically defined. We will leave it undefined within this note.

This system must also supply the L2 trigger. It must serve as the default CFT L2 preprocessor and as such send the list of 150 found L1 tracks to the L2 global processor. It has some 20 us after a L1 Accept to perform this task. It must also supply a list of tracks to the SVTpp for use as data filters and seed tracks. The SVTpp needs the filter data before the silicon data arrives which is about 2 us after a L1 Accept.

2. Functional Description

The tracks are found for each CFT sector on each of 80 FE trigger boards which are located in crates on top of the VLPC cryostat. The track information from the FE boards is sent over fast serial links to 16 receiver, CFTrec, boards located in crates on the detector platform. Each pair of CFTrec boards is connected over the crate back plane to a CFT Trigger Concentrator Boards, CFTcon. There are total of 8 CFTcon boards. The CFTcon serve two separate clients. They count the number of tracks from the CFTrec, count them, and pass the counts on to the Trigger Manager, CFTTM, and they pipeline the track list for transmission to the Silicon Vertex Tracker preprocessor, SVTpp, upon the receipt of a L1 accept.

Figure 1 shows a cartoon of the hardware and the links between the pieces. The boxes inside the dotted box are part of the system described in this note. The other parts already exist or are being planned as parts of other systems. Parts of this system are used exclusively for L1 triggering, parts for L2 and parts combine L1 and L2 functionality.

Figure 2 shows a functional description of each of the parts of this system durring L1 live time running. For this part of its operation the system acts as a L1 trigger. Figure 3 shows a functional description of this system when a L1 accept is received. For this part of its operation it acts like the front end of a L2 preprocessor for the CFTpp and the SVTpp.

2.1 Front End, FE

Each of the 80 FE's receives the analog signals from the VLPC's and finds a list of 6 tracks. Each track is represented by a 16 bit number which gives its momentum and its phi value at the outer layer of the CFT. Also included are bits which indicate a match with CPS clusters. Table 1 lists the bits.

The list of six tracks is transmitted from the FE's each crossing to a receiver board, CFTrec. A fast serial link using a copper line is used for this transmission. The transmitter and receiver daughter boards are designed and built by the University of Arizona for the Muon trigger system The daughter board and supporting logic on the mother board require about 4" by 4" and a special coaxial cable connection at the front panel.

2.2 CFT Receiver board, CFTrec

Each of the 16 CFTrec boards receives the track lists from 5 FE boards. There the information is immediately re-transmitted over two serial links to the Muon L1. Therefore each board has 5 receiver and 10 transmitter daughter boards. Figure 4 shows a block diagram of the CFTcon functionality.

The CFTrec next determines if the tracks in the list from each FE should be tagged as isolated. It looks at the list from each FE that has one or more tracks. If none of the next one or two neighbors on either side has a track the tracks in the home sector list are flagged as isolated. The CFT isolation flag is based of course on comparison of CFT tracks in all the lists. The CPS isolation flag is based on a CFT track with a CPS high threshold cluster match on the home sector with a CPS high threshold cluster match on neighbor sectors.

Since each board only has information on 5 sectors back plane lines are used tom communicate from board to board and form a seamless isolation test. The track word is extended to 18 bits with the addition of the two isolation bits.

This board also sorts the track lists into four momentum bins which correspond to the four Pt thresholds of the L1 trigger terms.

The track lists are then transmitted over the custom crate back plane to the concentrator board, CFTcon. Figure 5 shows a block diagram of how the track information is sent over the back plane.

2.3 CFT Concentrator board, CFTcon

The track list from each CFTrec is sent over a back plane bus to the concentrator, CFTcon. The CFTcon generates four clocking signals a cycle which are passed to the CFTrec. The CFTrec which has 5 lists of from 0 to 6 tracks sends the first track on the first clock, the second on the second and so on until four tracks are passed. Accepting only 4 tracks from a list that is potentially 30 long may seem very inefficient but most of the time the list from each FE is 0 or 1 tracks long. Figure 6 shows a block diagram of the track processing on the CFTcon board.

2.3.1 CFTcon for L1

As the data comes from each bus it is processed. For the L1 trigger the CFTcon counts how many tracks are received, keeping 4 sums per Pt threshold. The first sum is the number of CFT tracks. The second sum is the number of CFT track with a CPS cluster set. This sum can be for the high threshold cluster matches or the low threshold cluster matches but not both. Similar sums are kept for the isolated versions of the tracks as well. At the end of the cycle it combines the sums from the two CFTrec boards and sends these 16 numbers to the CFTTM. The data block of 16 numbers is sent over a serial link using a copper.

2.3.2 CFTcon for SVTpp at L2

The CFTcon also pipelines the track lists as they are received for later retrieval for the L2 trigger. The pipeline is 32 crossings deep and is wide enough to hold the maximum 8 tracks received for each of 4 Pt bins. It is 32 deep by 32 words wide by 2 bytes per word or 2048 bytes in size.

The above operations take place continuously during the L1 live time. And are performed for the data from each crossing. When a L1 accept is received the process is paused and the CFTrec begin a different mode of processing. They pull the appropriate event from their pipelines and sort them by an interpolated phi value at the outer surface of the silicon detector. The SVTpp is segmented into 24 phi wedges. The CFTcon is segmented into 8 phi wedges. The tracks from one CFTcon board are sent to three SVTpp boards. The CFTcon sorts each track according to which SVTpp phi wedge the track points to. Either one of the three wedges it is linked to or to the wedge on the left or the wedge on the right. There are the five phi sort bins, Phi0, the wedge to the left, Phi1, Phi2 and Phi 3, the three wedges to which it is linked and Phi4 the wedge to the right. The tracks is bins Phi0 and Phi4 are then exchanged across the back plane. Since now phi bins 1 and 3 can have more than 8 tracks, the track lists in these two bins is reduced to 8 and the track lists are transmitted to the SVTpp. Figure 7 shows a block diagram of the functions of the CFTcon bards for the SVTpp.

The link to SVTpp is a serial link using fiber optics. The data from all three phi bins is sent over a single link, sending each phi bin in turn. The optical cable is passively split into 3 at the receiver end and connected to 3 SVTpp receivers. Each receiver picks off the data for its phi range and ignores the rest.

2.3.3 CFTcon for CFTpp and Global L2

The track lists assembled above for the SVTpp are simultaneously transmitted over a second link per CFTcon to the CFTpp. All sorting and reformatting for the L2 Global are done on the CFTpp boards. The data from the CFTpp is sent to the L2 Global over the GL2 board developed by D0.

2.4 CFT Trigger Manager, CFTTM

The CFTTM receives 16 numbers from each of the eight CFTcon's and sums them. After the sums are made each is compared to a cut number downloaded from the trigger framework. If the sum in any of the 16 meets its requirement the corresponding bit in the L1 AND-OR network term is set. The meaning of the individual AND-OR terms is given in table 1. Figure 8 shows a block diagram of the CFTTM.

The CFTTM receives the 16 numbers in a block of 96 bits. The 16 numbers are loaded as 4 bit fields in the first 4 words of the block. Table xx gives the format of the data block.

<u>The Muon Trigger Manager, MTM, board without modification is used as the CFTTM board</u>. And <u>the CFTTM resides in the Muon Trigger Crate</u> located on the east side of the detector platform. All of the external I/O with the exception of the eight links to the CFTcon are supplied and maintained as part of the Muon L1 system. The unique software used in the CFTTM's FPGAs is provided and maintained by the CFT trigger group while the common software is provided and maintained by the Muon L1 group.

3. Timing

The entire logic and data transfer chain for the CFT L1 trigger has 12 links each of which take approximately one crossing. Therefore the AND OR term is presented to the trigger framework about 1.6 us after each crossing. This is well within the maximum time allowed. The delivery of track information to muon is time critical. Figure 9 shows the end of delivery to muon L1 at 800 ns. This is later than they require, but this diagram is only approximate. The exact times for each stage and the time in transition between stages needs to be studied carefully.

4. Product Quality

The fiber hit information is input into the front of the trigger logic. At this point this represents the maximum fiber information. The fiber hits are formed into doublet hits which are send to the track equations. The track equations represent the maximal information known about any track. Each track's most precise momentum and position information is known at this point. But there are thousands of equations and no method has been found to extract this information from the logic chip which created it. From this point on the information content of the data is reduced to enable the extraction of the momentum and position information with the least amount of logic resources balanced with the precision needed for Physics. Below are listed the major steps where information is lost:

At each phi bin only the Highest Pt track is retained. In the present design each phi bin is one fiber of 44 in each sector. This is about 980um or 0.10 degrees. Also this phi coordinate is at the outer layer, where the radius is about 550mm. *NOTE: we have not completed an actual design to see if 44 phi bins are possible here. We may have to reduce the 44 phi bins down to 16.*

Per FE sector only 6 tracks are kept. Several methods of picking these 6 candidates are under study to determine the resources needed and determine what inefficiencies each introduces. *This is the point at which the tracks are sent to Muon*.

The 6 tracks of above are separated into 4 bins by there Pt and then only 4 tracks per 5 FE sectors per Pt bin are kept. Up to 30 tracks are reduced to as few as 4 tracks or as many as 16 tracks. *This is the point at which the number of tracks is counted for comparison to the L1 Trigger Terms*.

The impact of each of these information reductions need to be studied. Do they cause undue inefficiencies for normal events? For Busy events?

5. Summary

This note presents a top down overall design of the L1 trigger for the CFT and CPS with added functionality for the delivery of tracks found in the L1 CFT to the L1 Muon Trigger, the L2 Global Trigger and the L2 SVTpp. The design leaves the FE Trigger boards and their crates as they were in earlier designs for the FE only. It has some time impact on the muon trigger since the delivery of tracks to them is now later in the FE trigger logic chain. It requires crates to house 24 VME boards somewhere on the east platform.

Format of Data Words from CFT Front End

Bit #		Field Bit #	Use	
15	Most Sig.	0	Track Found Flag [1=found]	
14		3	High Threshold Track Match	CPS cluste
13		2	High Threshold Track N / S	
12		1	Low Threshold Track Match	
11		0	Low Threshold Track N / S	
10		0	Sign of the Pt for Track	
9		3	Inner (A) Layer Offset from Outer Layer Bin	
8		2		
7		1		
6		0		
5		5	Outer (H) Layer Phi Bin	
4		4		
3		3		
2		2		
1		1		
0	Least Sig.	0		

Table 1. Definition of bits for the 16bit CFT/CPS track word. Six bits are used to identify the phi position. Five bits are used to identify the momentum including its sign. Four bits are used to identify matches with the CPS. And one bit is used to tag the word as containing valid track information.

	Bit				
Word	**15-12**	**11-8**	**7-4**	**3-0**	
6	-	-	-	-	Spare
5	-	-	-	-	Spare
4	Pt 1	Pt 2	Pt 3	Pt 4	CFT
3	Pt 1	Pt 2	Pt 3	Pt 4	CFT/CPS
2	Pt 1	Pt 2	Pt 3	Pt 4	isoCFT
1	Pt 1	Pt 2	Pt 3	Pt 4	isoCFT/CPS

Table 2. Definition of data block from each of the CFTcon to the CFTTM. Each Pt is a 4bit unsigned integer.

Term Number	**Description of Term**			
Term_15		CFT above	Highest	Pt Threshold
Term_14		CFT above	High	Pt Threshold
Term_13		CFT above	Medium	Pt Threshold
Term_12		CFT above	Low	Pt Threshold
Term_11		CFT/CPS above	Highest	Pt Threshold
Term_10		CFT/CPS above	High	Pt Threshold
Term_9		CFT/CPS above	Medium	Pt Threshold
Term_8		CFT/CPS above	Low	Pt Threshold
Term_7	isolated	CFT above	Highest	Pt Threshold
Term_6	isolated	CFT above	High	Pt Threshold
Term_5	isolated	CFT above	Medium	Pt Threshold
Term_4	isolated	CFT above	Low	Pt Threshold
Term_3	isolated	CFT/CPS above	Highest	Pt Threshold
Term_2	isolated	CFT/CPS above	High	Pt Threshold
Term_1	isolated	CFT/CPS above	Medium	Pt Threshold
Term_0	isolated	CFT/CPS above	Low	Pt Threshold

Table 3. The definition, version 1.0, of the AND-OR terms from the L1 CFTTM.

Luminosity	Crossings	Other	Av per 5	Ratio of 4	Ratio of 8	Ratio of 16
2.00E+32	108		4.72	0.4896	0.9483	1.0000
2.00E+32	108	1/40	1.19	0.9552	0.9998	1.0000
2.00E+32	36		7.07	0.1669	0.7202	0.9989
2.00E+32	36	1/40	4.53	0.5255	0.9581	1.0000
2.00E+33	108		13.54	0.0025	0.0774	0.7940
2.00E+33	108	1/40	10.00	0.0293	0.3330	0.9730

Table showing the number of tracks per event per 5 sectors for all tracks down to 1.5 GeV. This table is based on numbers for one trigger event plus dijet MC data for the background interactions. The MC backgrounds are weighted by relative cross section for parton energy and are weighted for number of events by a Poisson distribution for the luminosity. The trigger event is arbitrarily assigned 15 global tracks on average and either 0.6 or (15/40) per sector on average. Under the assumptions that went into this table, keeping 4 tracks per Pt bin per 5 sectors (Ratio of 16) is 100% efficient for run II even at 36 bunches. It is also close to efficient for run III with this low trigger threshold.

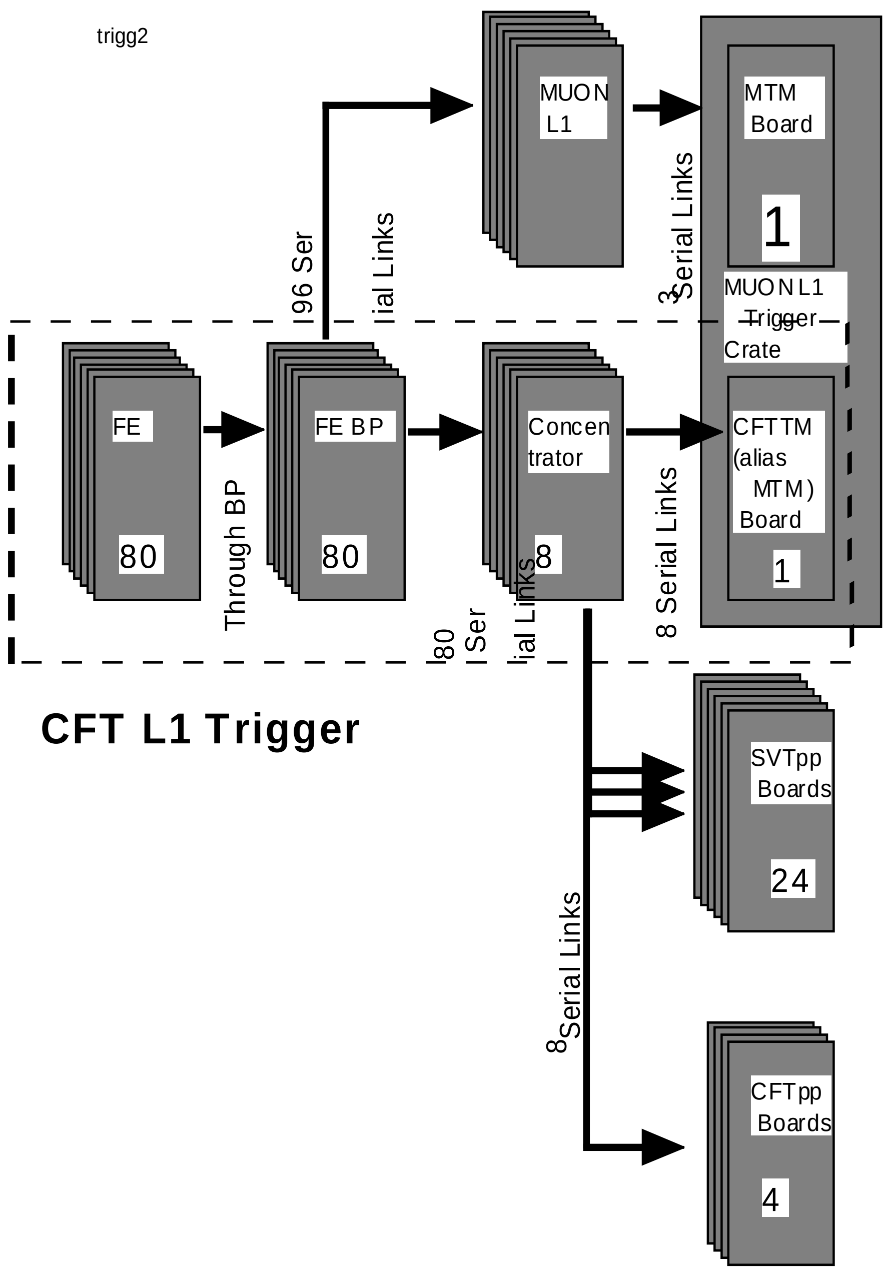


Figure 1. Cartoon of the hardware for the CFT L1 and L2 system. The parts in the dotted box are parts of this system. The parts in stippled boxes are being built or planned as part of other projects.

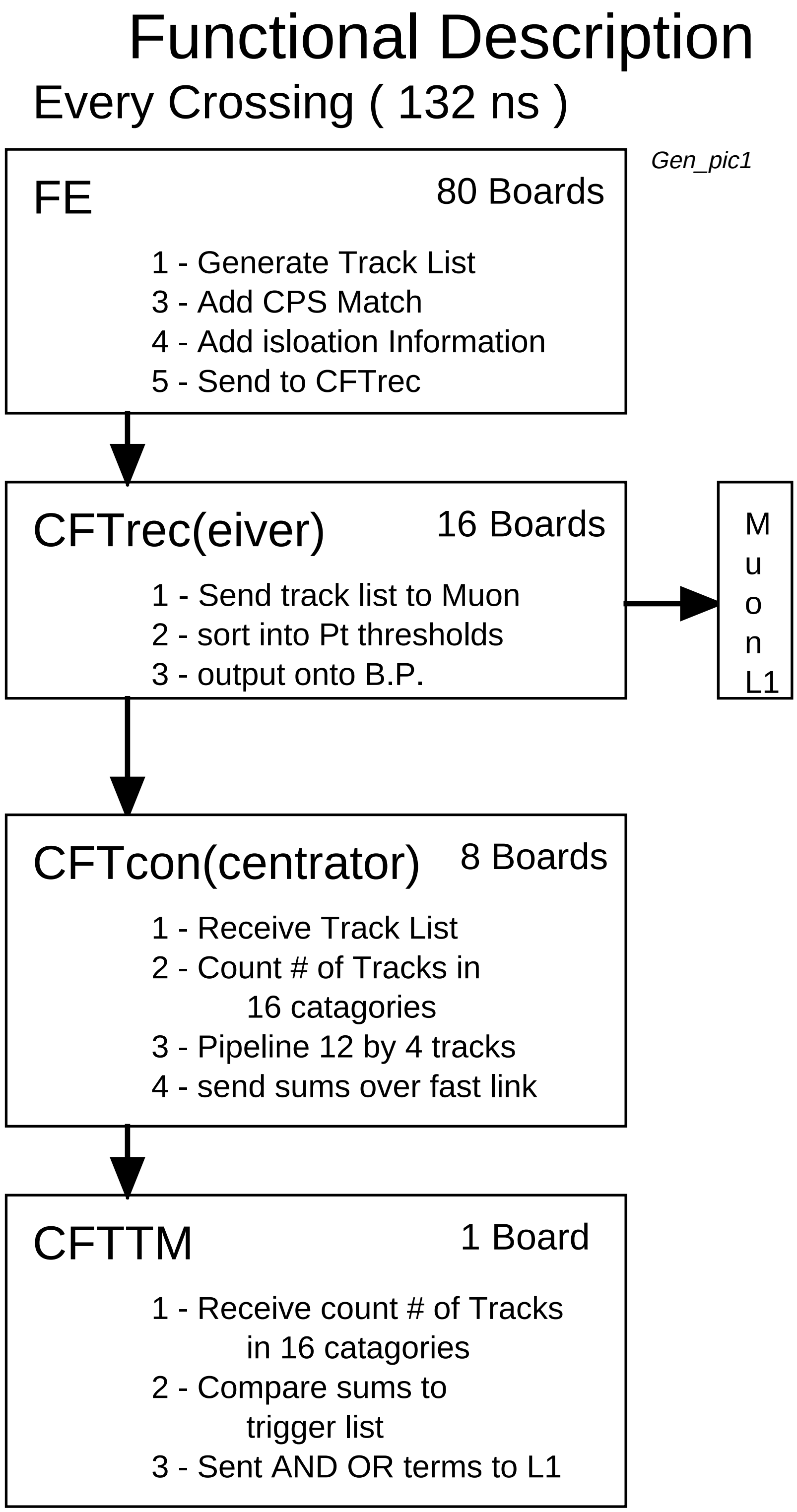


Figure 2. Functional description of the main blocks of the CFT L1 Trigger system. This figure shows the functions carried out for each crossing cycle during L1 live time.

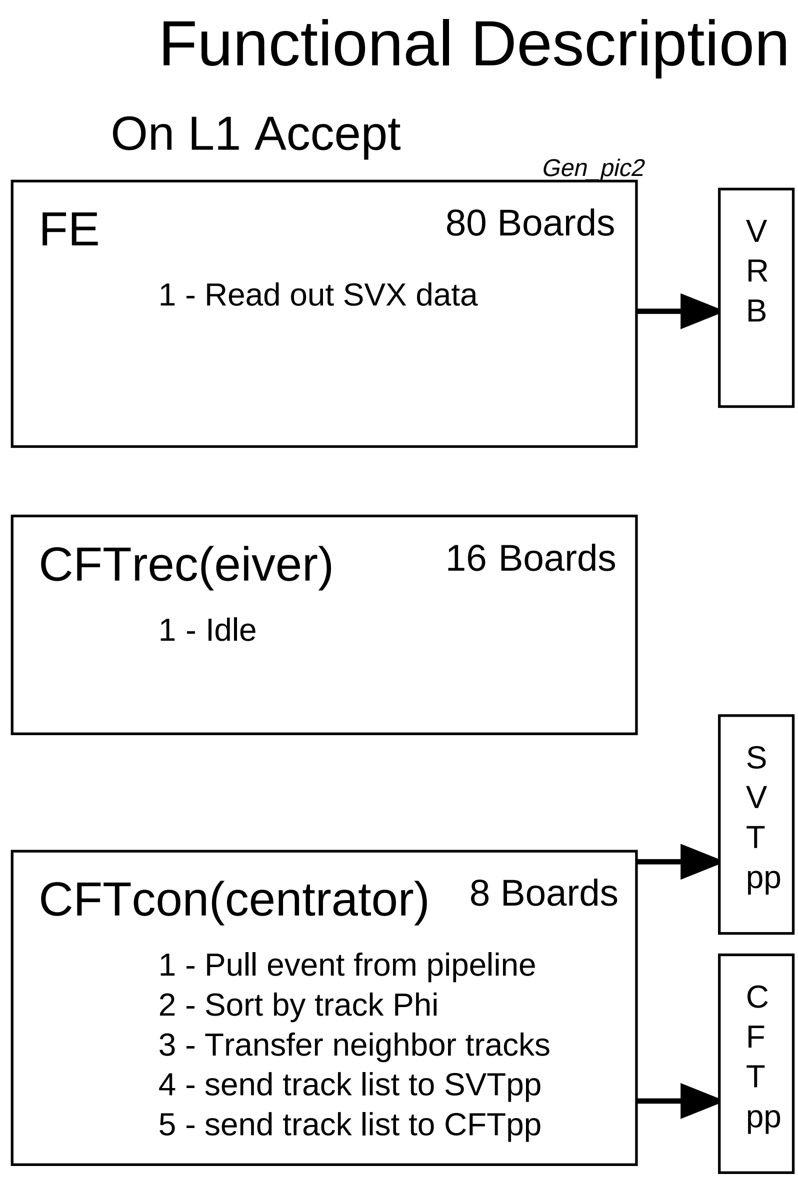


Figure 3. Functional description of the main blocks of the CFT L1 Trigger system. This figure shows the functions carried out after a L1 accept is received.

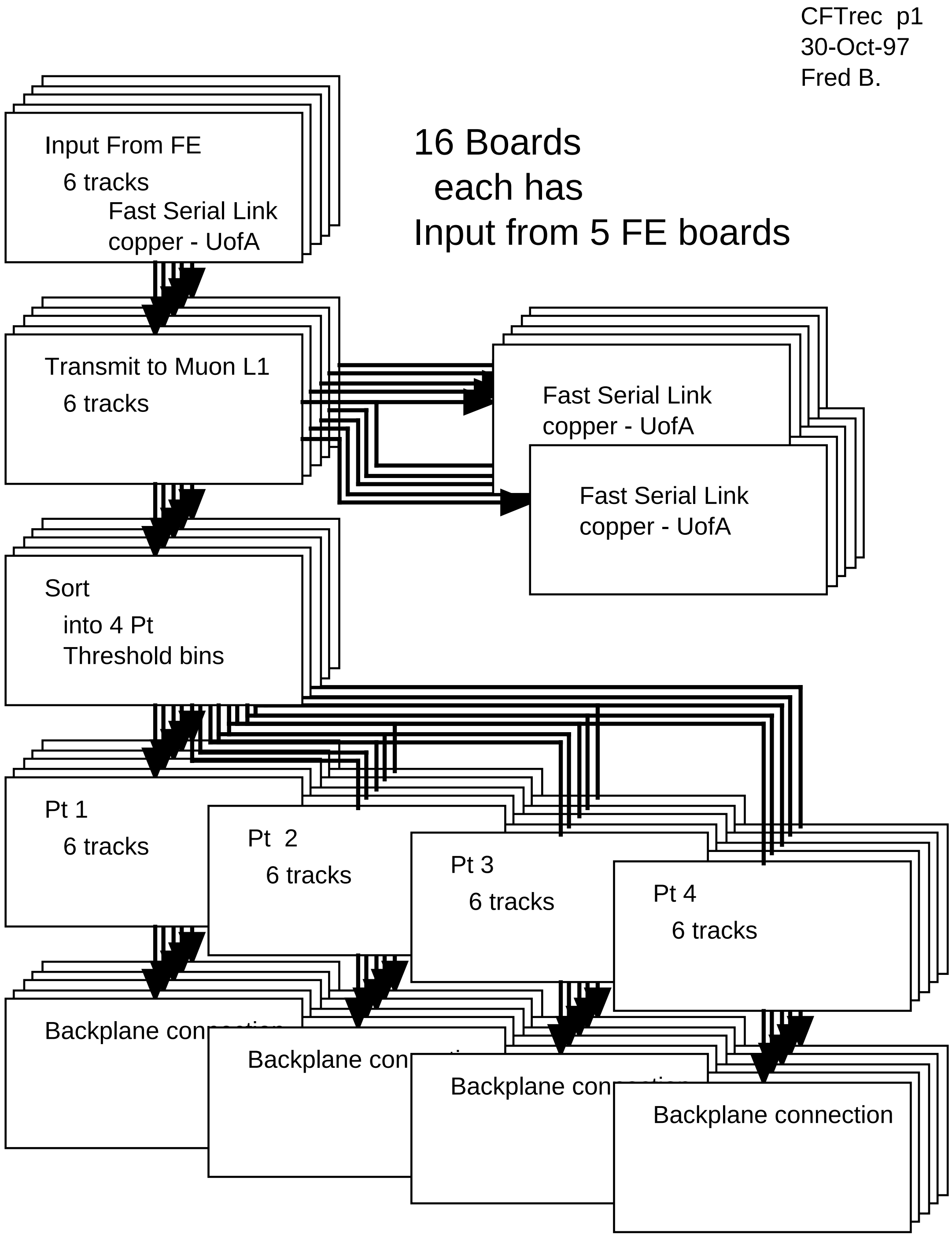
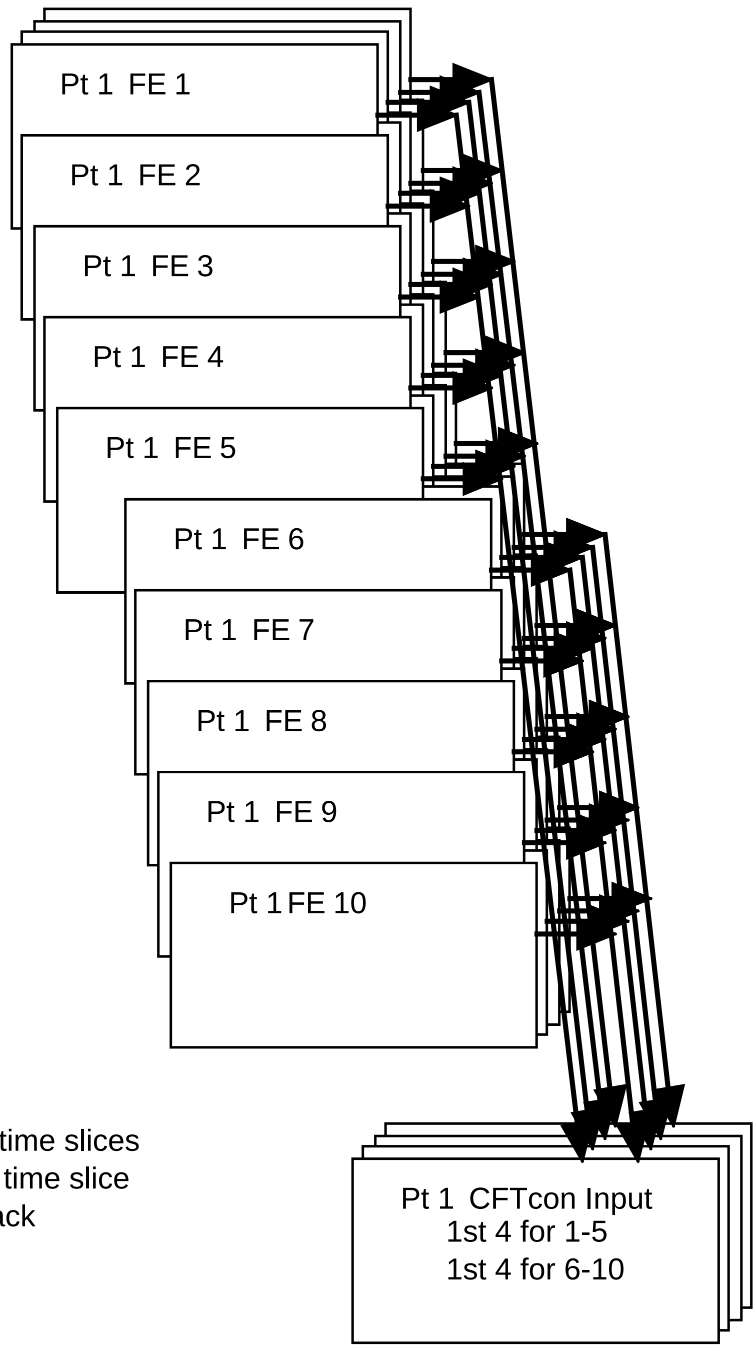


Figure 4. Block diagram of the functionality of the CFTrec boards. Each board receives the data from 5 FE boards and retransmits that data to 10 muon receivers. Each board also sorts the data and transmits it over the crate back plane.

CFT_BP
30-Oct-97
Fred B.



Transfer in 4 time slices
16 tracks per time slice
16 bits per track
-> 256 lines

Figure 5. Block diagram of the track information over the back plane from two CFTrec boards to one CFTcon board.

CFTcon L1
30-Oct-97
Fred B.

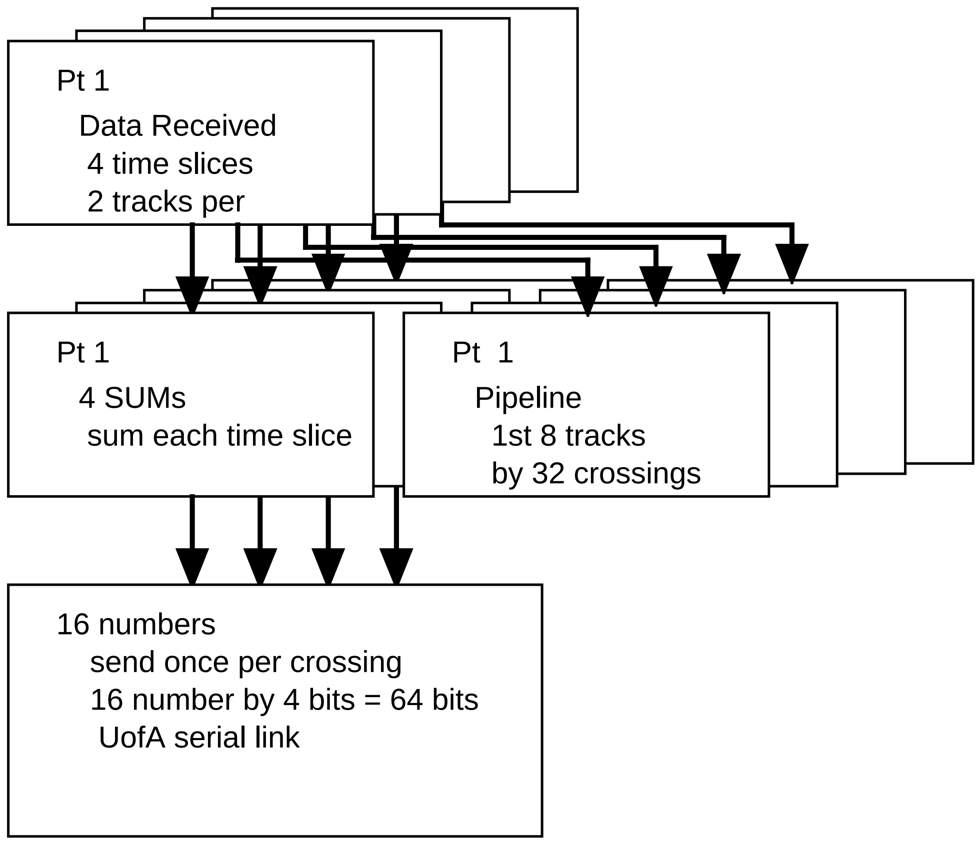


Figure 6. Block diagram of the track processing in the CFTcon board. As each track is received the 16 sums for the L1 are updated and the track index is stored in a pipeline. At the end of a crossing cycle the 16 sums are transmitted to the CFTTM.

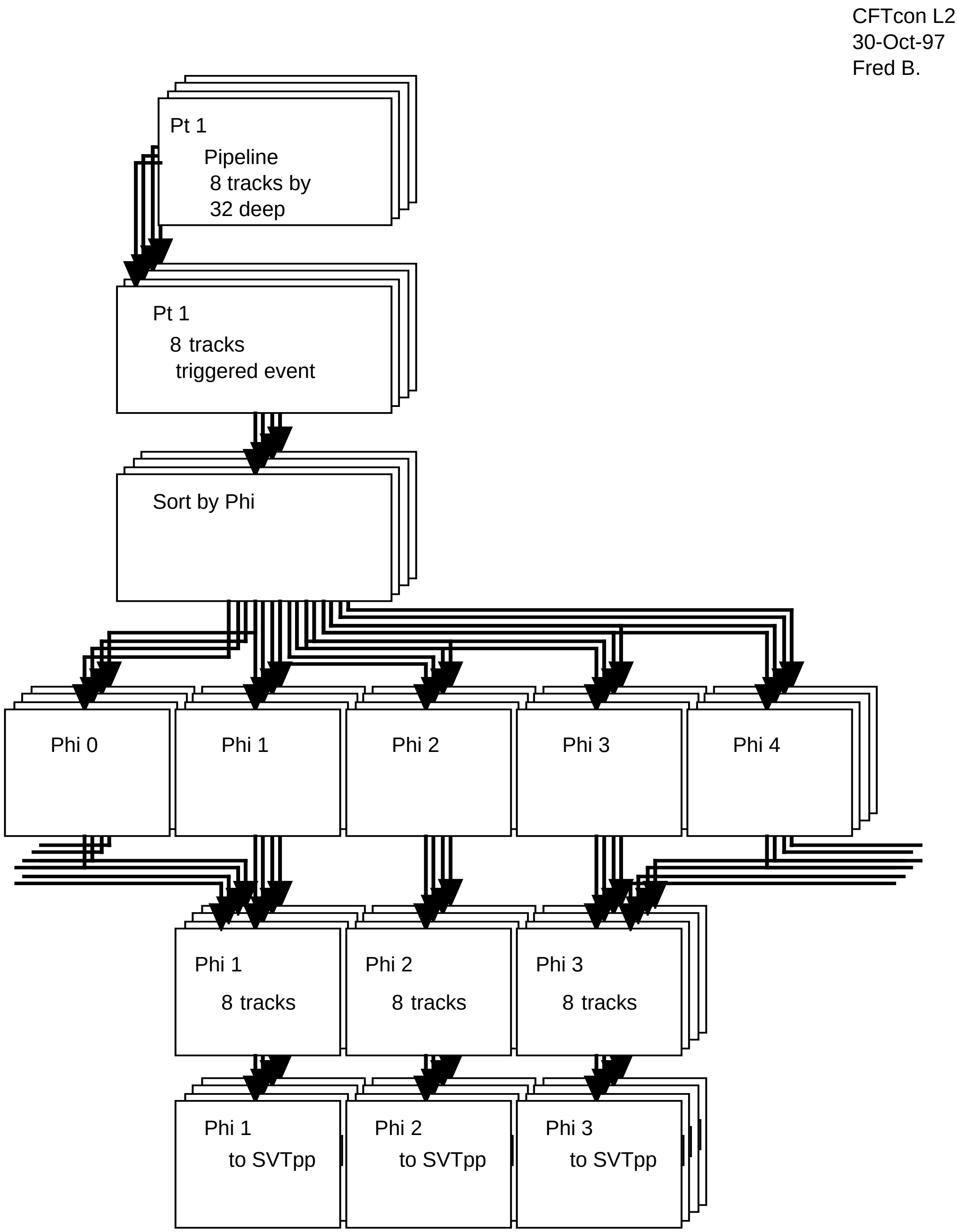


Figure 7. Block diagram of the CFTcon board upon a L1 accept. The appropriate event is pulled from the pipeline and sorted by phi intercept in the silicon detector. Tracks which point outside the correct phi slice are sent to the neighbor CFTcon board for inclusion in its list. Finally the list is reformatted and sent to the SFTpp.

CFTTM
30-Oct-97
Fred B.

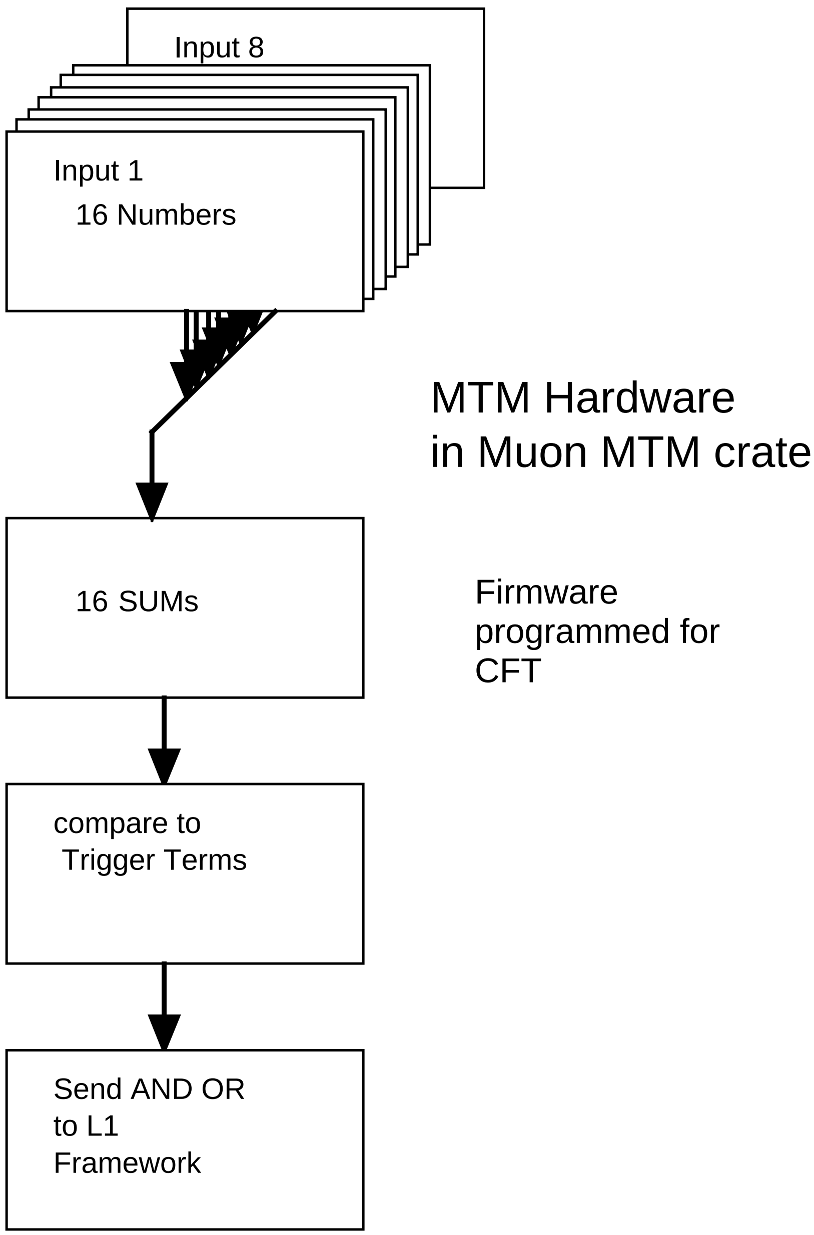


Figure 8. Block diagram of the CFTTM. The Muon TM hardware is used and the board is placed in the muon L1 crate. The onboard software for forming the trigger is unique for the CFTTM.

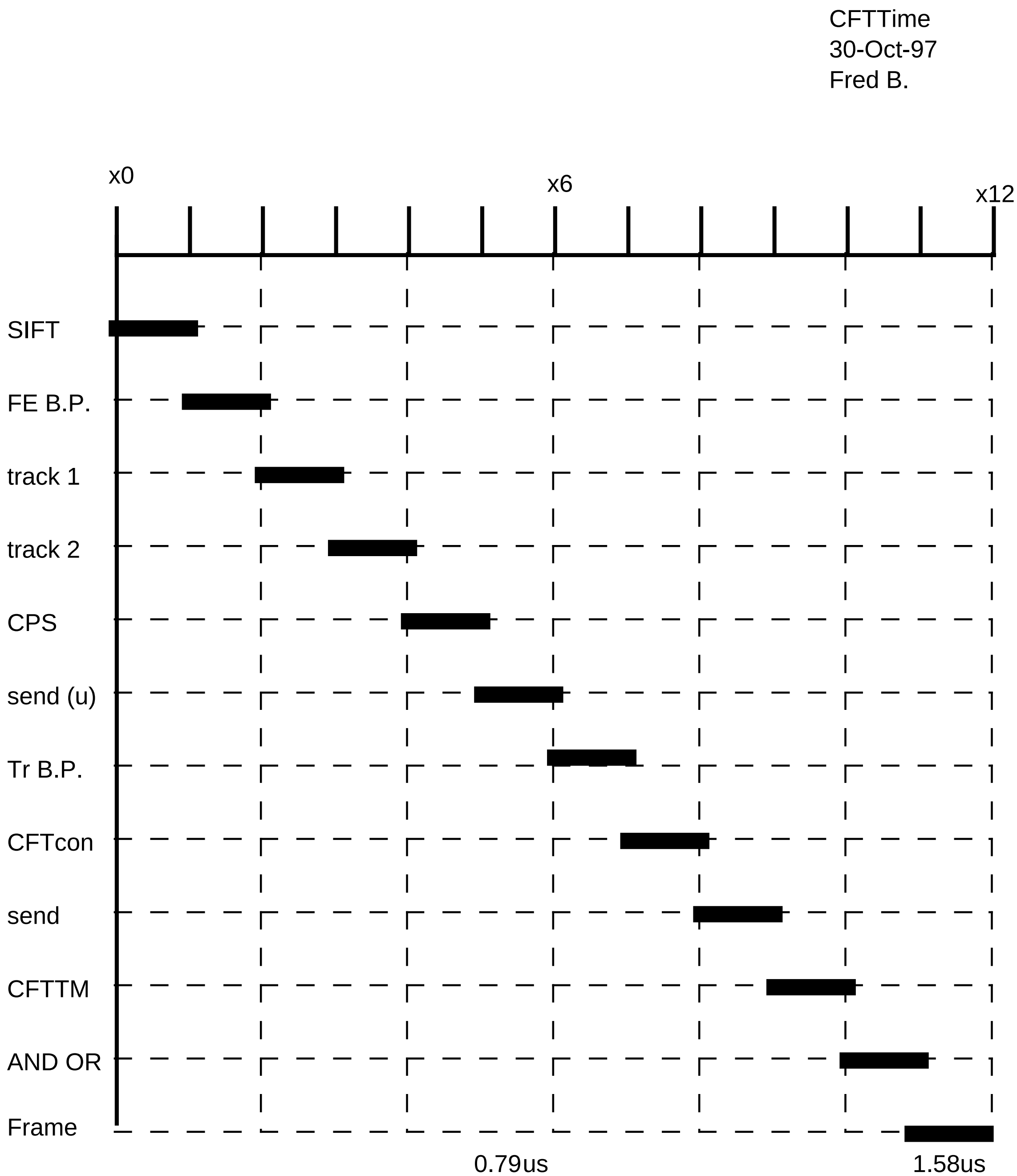


Figure 9. Simplified timing diagram of the times needed for form the L1 trigger. Send (u) is also the time at which the track information is sent to Muon L1.