ProtoDUNE-SP Central Trigger Board

Capabilities and Proposed Trigger Scheme

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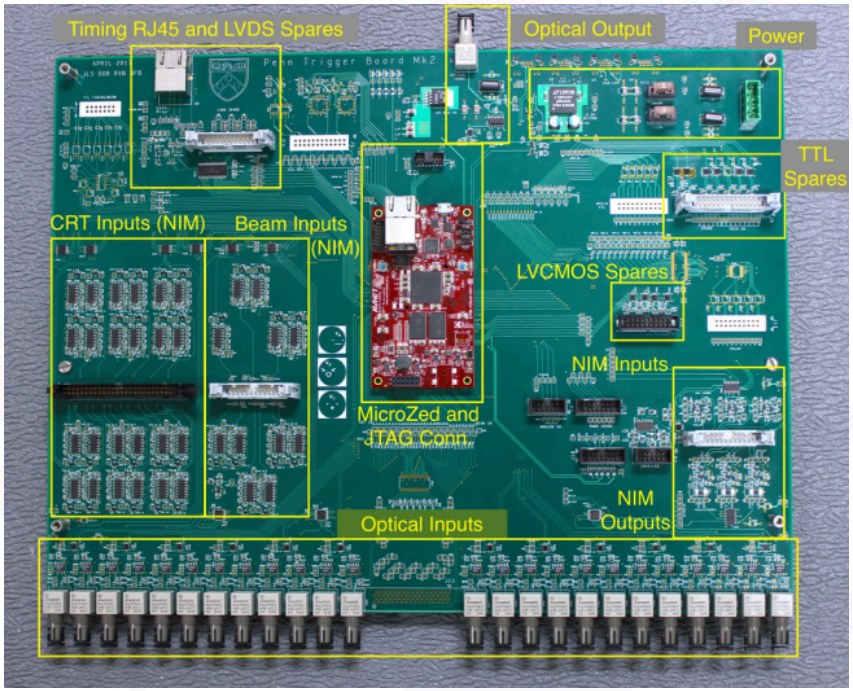
The Central Trigger Board (CTB)

- Second (revised) iteration of trigger electronics used in DUNE 35-ton
- Uses a MicroZed
  - Zynq-7000 SoC
  - ~100 I/O ports
  - Dual-core ARM processor
  - Gigabit ethernet
  - 1GB of RAM
- **Motherboard** implements hardware interface with different systems
- FPGA implements trigger logic, interface with timing
- CPU/Software manages FPGA configuration and communication with DAQ software

This board decides when we have something worth recording



Jon Sensenig

Definitions

Channel Input to the CTB. Each subsystem has several channels.

Coincidence Window Time period (in clock cycles) that each individual input is shaped to permit coincidences

Reshape time Same as above. Historically also known as `trigger gate`

Delay Time period (in clock cycles) that a signal is delayed before being passed to the trigger logic.

Prescale Number of triggers that are ignored before accepting one and propagating it to trigger distribution

LLT **Low Level Trigger**. Trigger at subsystem level (PDS, CRT, BI)

HLT **High Level Trigger**. Global trigger, built from LLTs.

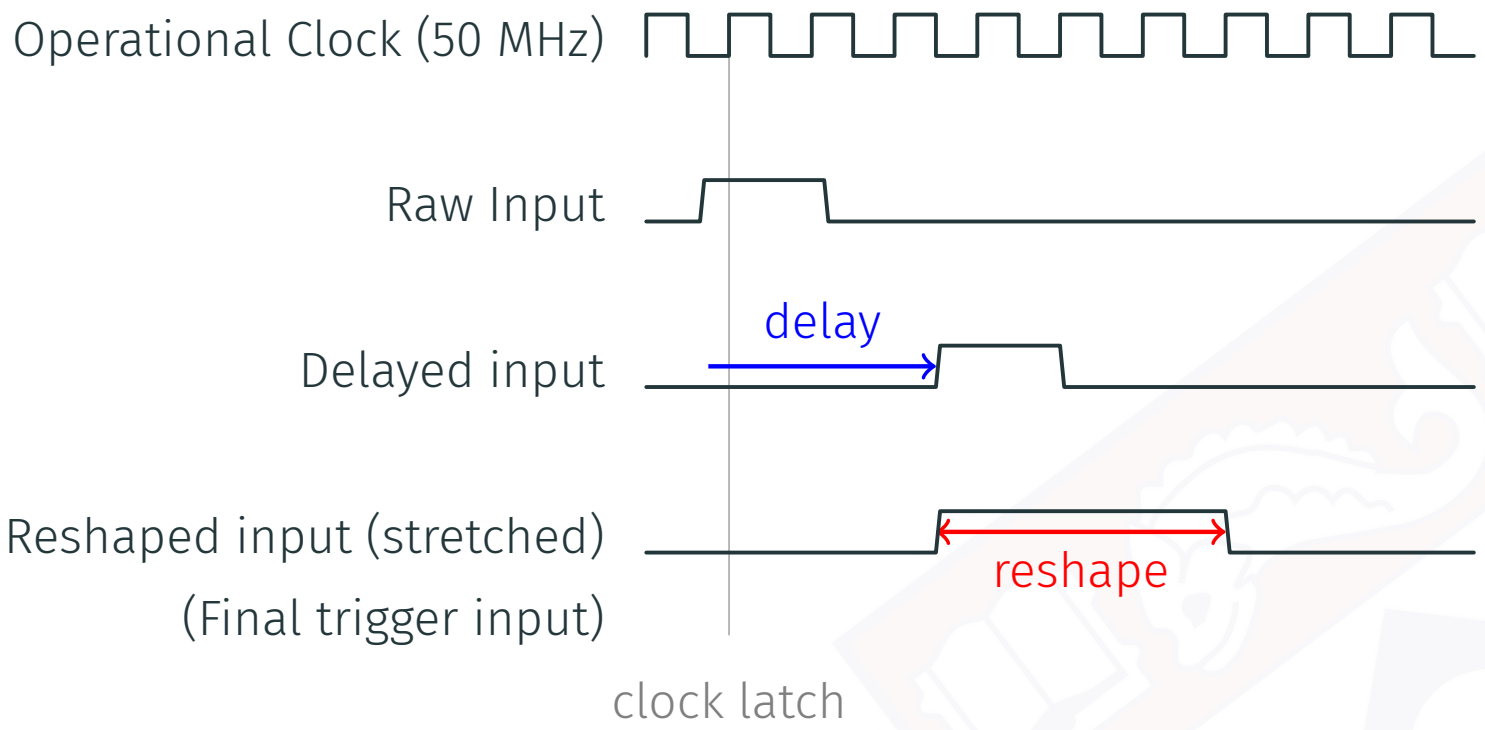
Board Reader artDAQ interface to the CTB (config and data handling)

Calibration Stream Aka `Monitoring Stream`. Data stream for monitoring of CTB activity. Likely outside artDAQ.

Important Remarks

The CTB is a synchronous system. Asynchronous inputs are latched and processing is begun on rise of the operational clock (50 MHz)

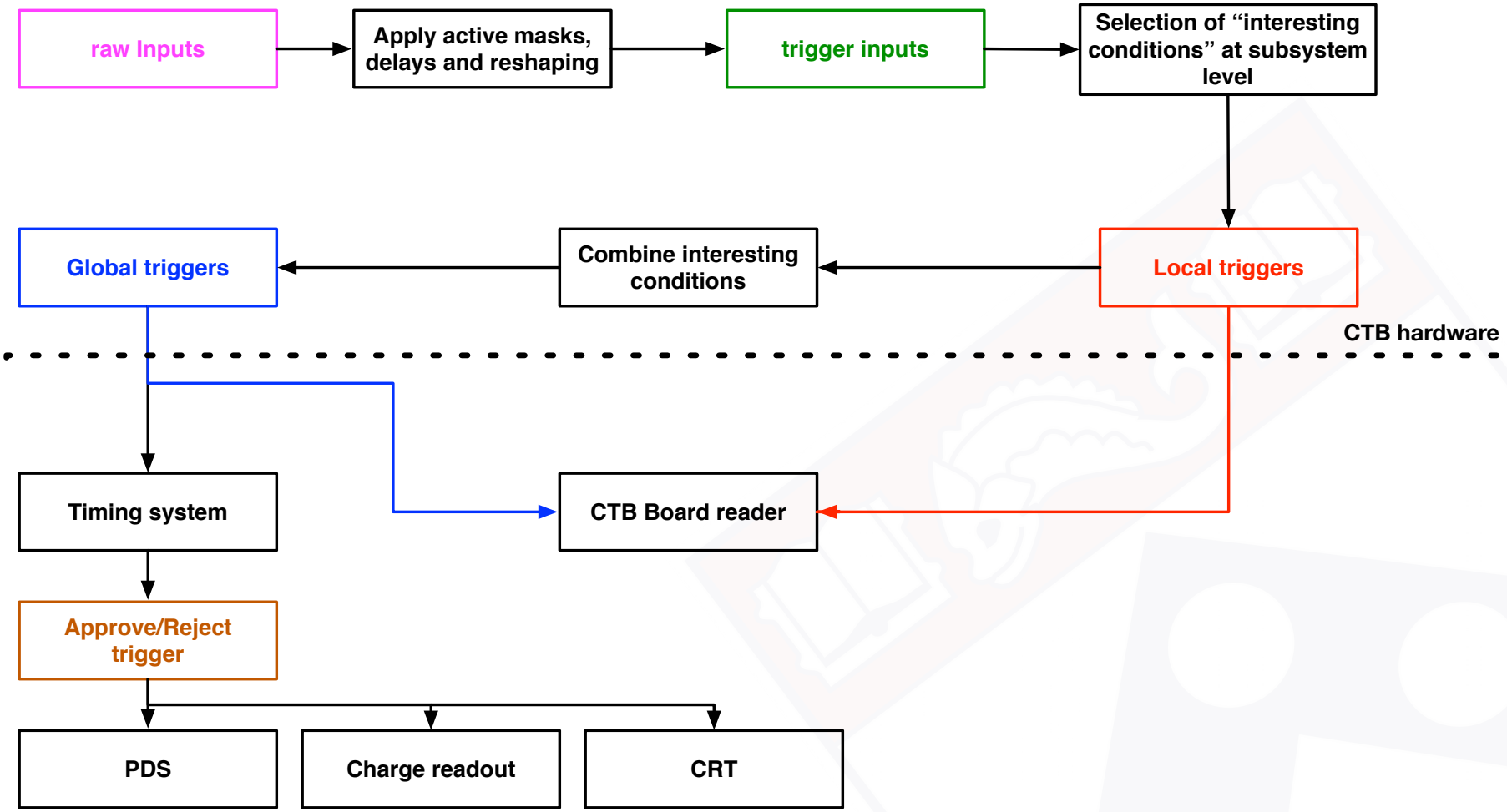
Trigger inputs



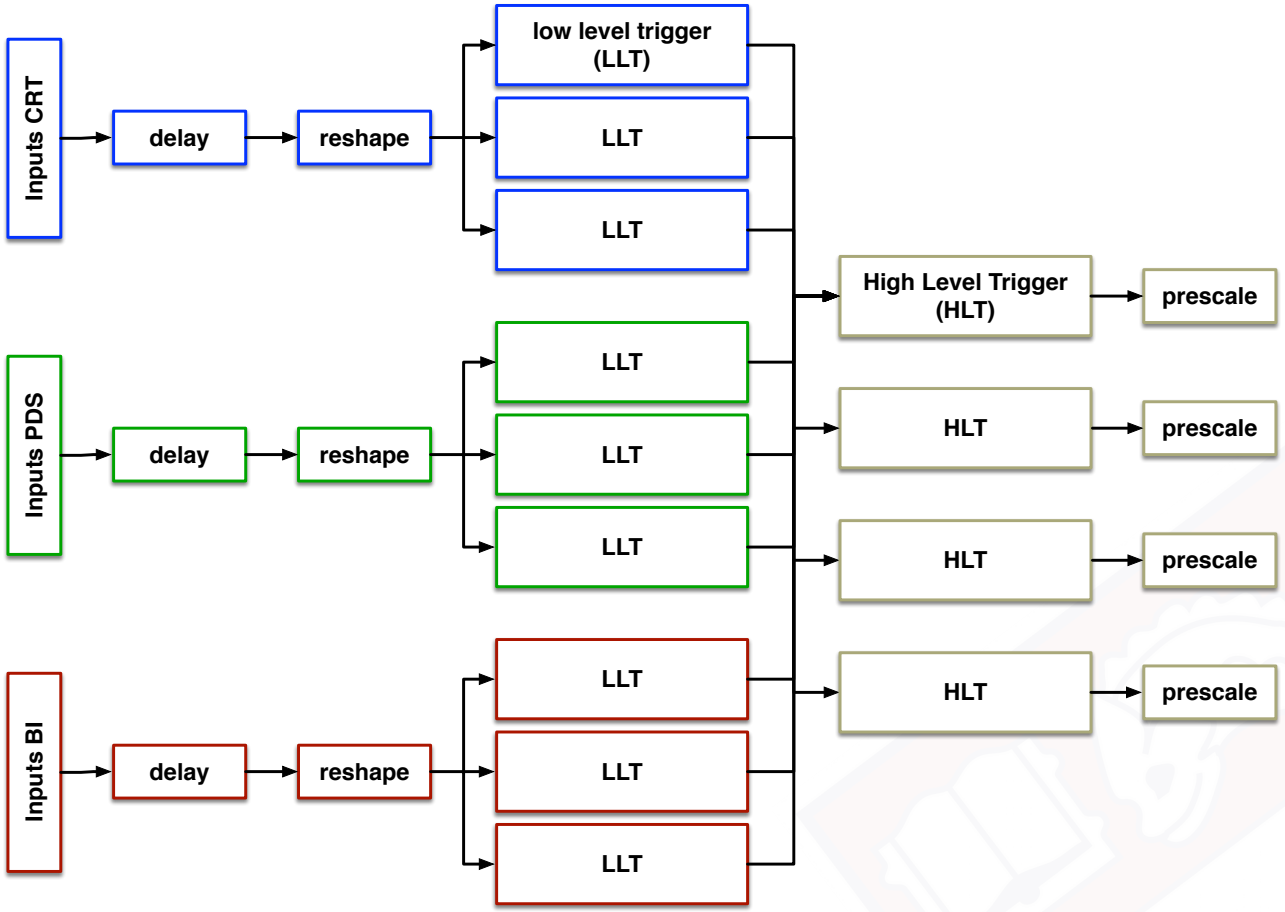
CTB trigger design principles

- Use multi-layered trigger
  - Multiple LLTs (each dedicated to a single input subsystem)
  - Produce HLT (global triggers), by combining one or more LLT
- Each subsystem can have several LLTs
- The CTB can produce several types HLTs
- Only the HLTs are passed on to the timing system
- The timing system can **veto** any trigger from being propagated
  - For example, if another trigger was issued recently, if the charge readout is busy, etc
- Both LLTs and HLTs are recorded/reported to the board reader
  - So we can recover at least the history of everything the CTB ”saw”, even if a global trigger was not issued
  - **Everything that the CTB sends downstream is timestamped**
- Planning to also produce `random triggers`.
  - Zero bias. Trigger on noise, when there are no real triggers.
  - The very first trigger to be put in place (next week)

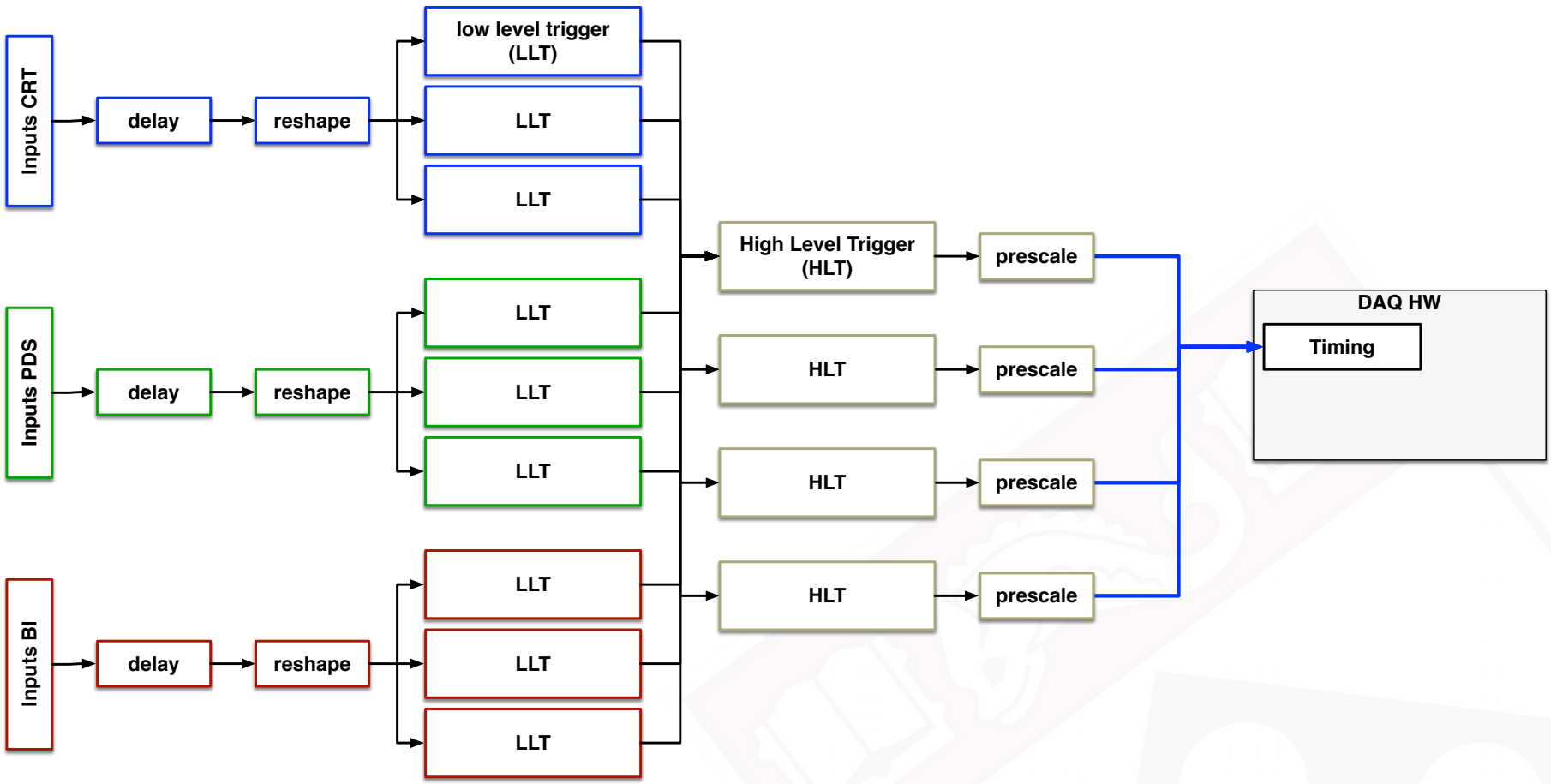
How the CTB works



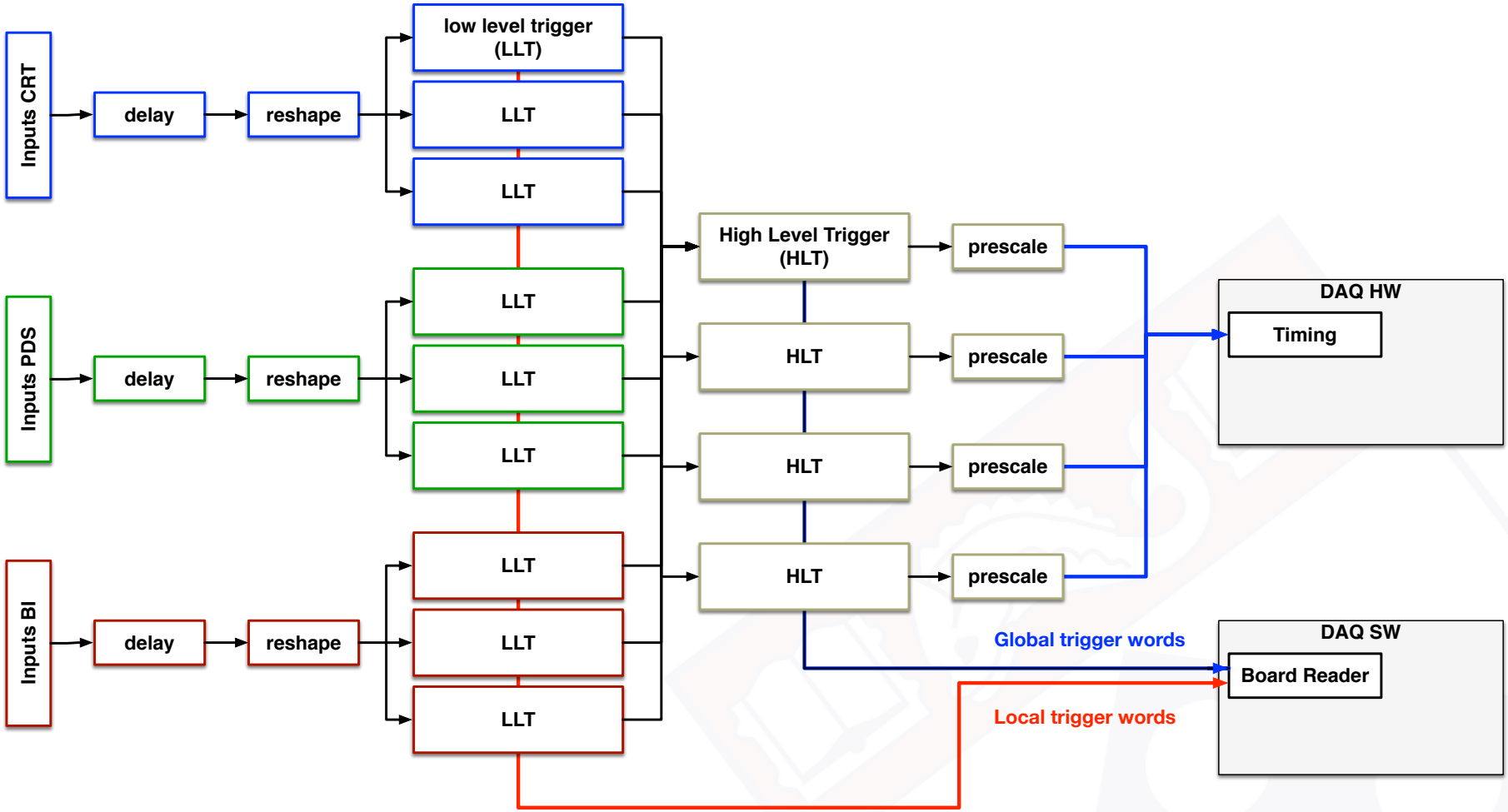
How the CTB works (a more technical view)



How the CTB works (a more technical view)



How the CTB works (a more technical view)



How to build triggers?

- Possibilities are endless. Have to draw the line somewhere.
  - Current design allows for a lot of flexibility
  - Well defined use cases are still necessary
- Two generic types of triggers:

Mask Based A bitmask indicates which inputs can contribute to a trigger

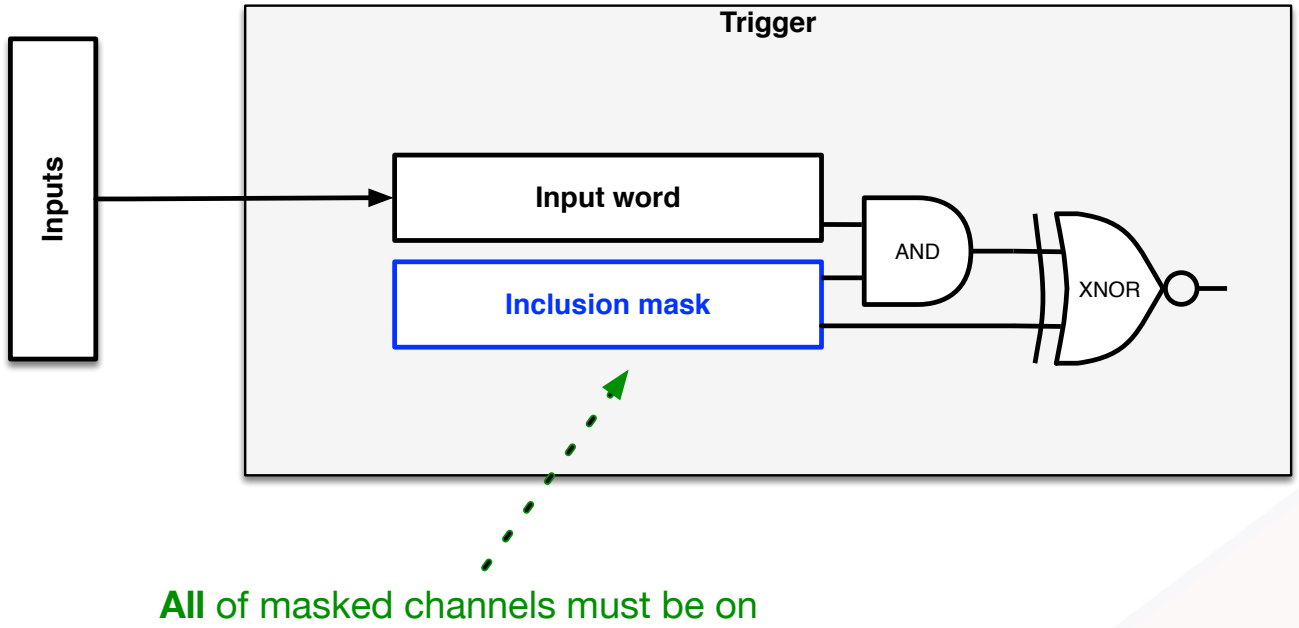
Count Based Number of active inputs activate a trigger

- Each of these types represents a distinct firmware block.
- Can have multiple instances (both per subsystem and globally), and exact configuration is performed at run start.
- However, the number of each type of triggers must be defined beforehand for each subsystem
- Need input from the physics groups!!!
- CTB inputs are not ”raw” inputs. In some cases they may have already built-in coincidences (eg. CRT)

Mask based triggers

- A bitmask indicates which inputs can contribute to a trigger
- At subsystem level (LLT), the bitmask represents the different subsystem inputs
- At high level (HLT), the bitmask represents the different LLTs
- Masks can be either `inclusive` (all masked inputs must match), or `simple` (any of masked bits enables a trigger)

Mask based triggers (inclusive trigger)



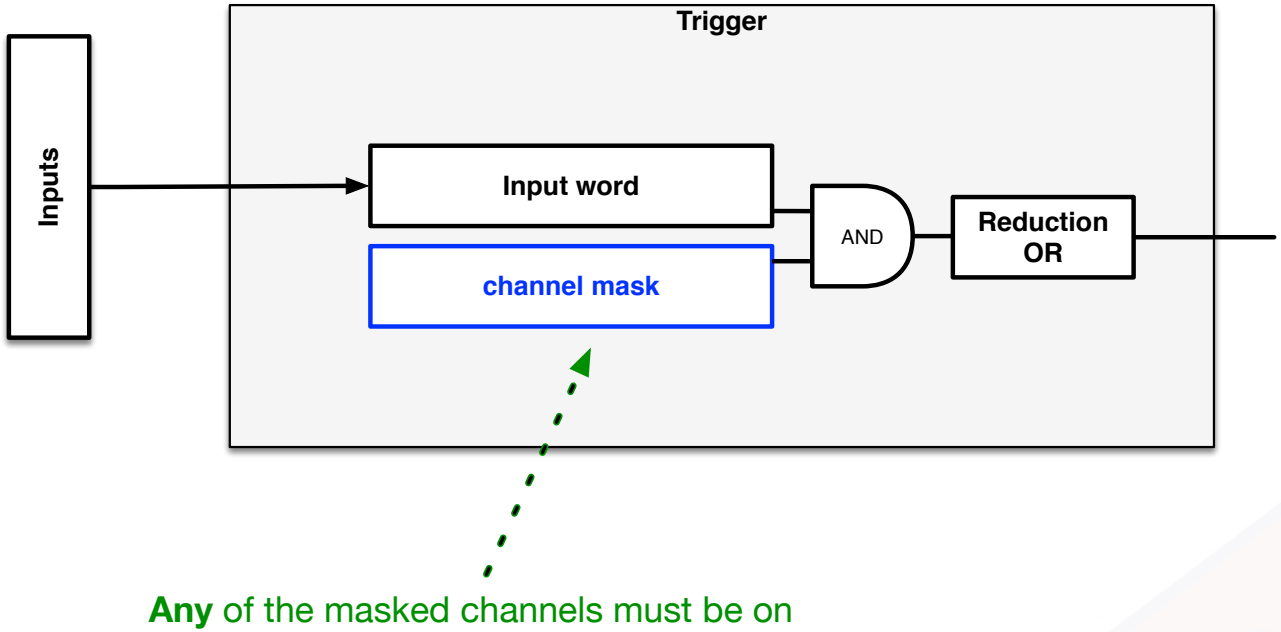
Examples

LLT/BI Beam is on and Cherenkov detector X has a signal

LLT/CRT +X plane has signal **AND** -X plane has signal (horizontal, through going muon)

HLT BI is on, Cherenkov X is on, and through going muon on CRT (LLT BI 1 **LLT** CRT 1)

Mask based triggers (simple trigger)



Examples

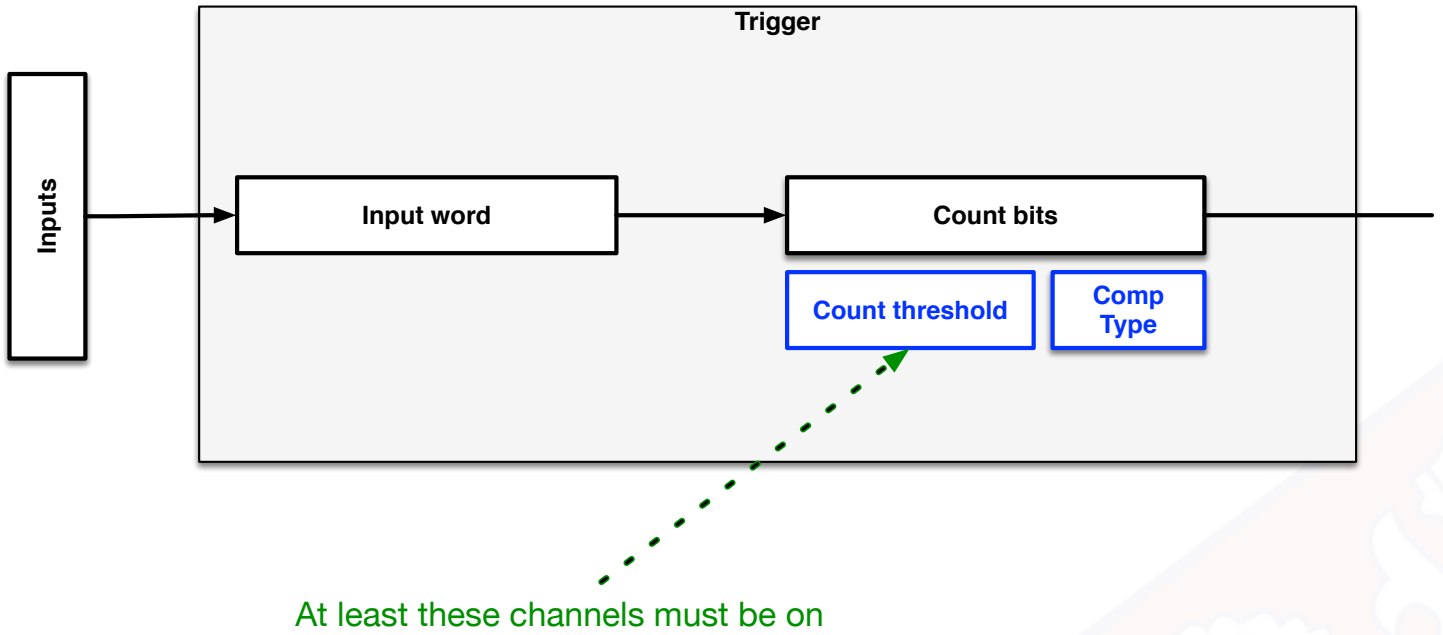
LLT/CRT Any CRT horizontal panel is on

LLT/PDS Any SSP is on

HLT Should be avoided its use as it is too broad and will likely cause large number of triggers

- This is the equivalent of saying ”fire a trigger whether any of these conditions happen.”

Count based triggers (only for PDS)



- Only planned to be used on the PDS subsystem
- Expensive in terms of logic

Examples

LLT/PDS At least/exactly/no more than N SSPs on

High Level Triggers

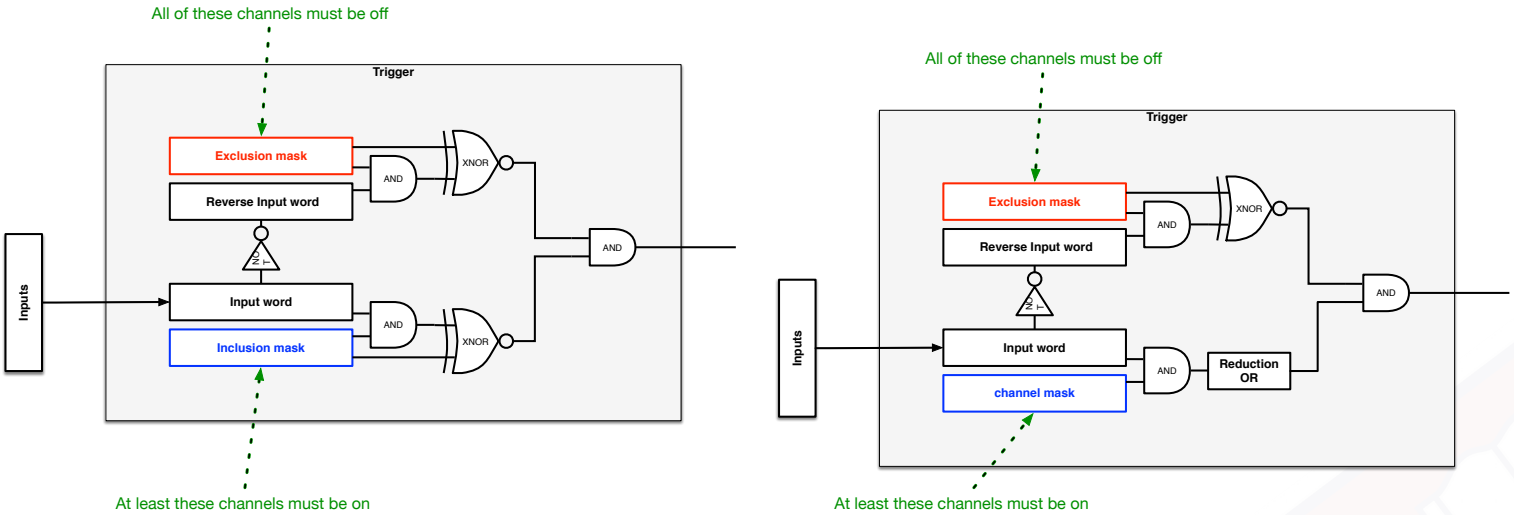
- These triggers are completely dependent on the configured LLTs for each subsystem
  - Use cases are more complex
- Triggers should consist mostly of mask based triggers
- **There is one hardcoded LLT in the HLT mask: beam ON/OFF**

Examples

- Beam on and no more than 2 SSPs on
- Beam on, Cherenkov A on and at least 4 SSPs on
- Any vertical CRT and any number of SSPs on

While drafting this, one extra use case was found...

Excluding triggers (only for HLTs)



All of requested asserted LLTs were ON, and **ALL** the requested deasserted LLTs were OFF

Examples

- All top CRTs and any PDS **but no beam**
  - Note that this implies the following LLTs
    - LLT on CRT selecting all top CRTs
    - LLT on PDS selecting any PDS
    - LLT on BI selecting **at least** the beam gate
- To be used sparingly! Clear requirements needed.

Putting it all together

Examples of Low Level Triggers

- Beam ON and BI detectors 1,3 and 5
- Any of beam detectors A, B, C and D
- At least N PDs
- Exactly N PDs
- Planes A and B of CRT
- Any horizontal/vertical panel of CRT

Important!!!

Low level triggers are internal CTB constructs. They are **not** distributed to the other systems.

- But they can be if an appropriate HLT mask is defined (commissioning use case)
- They are still recorded to artDAQ through the CTB data stream (regardless of global trigger)

Putting it all together

Examples of High Level Triggers

- Through going muon on horizontal CRT planes and PDS but NO beam

  LLT1 Beam ON (built-in)
  LLT2 At least 1 PDS
  LLT3 Any CRTs on one side of the cryostat
  LLT4 Any CRTs on other side of the cryostat
  HLT Mask in : LLT2-4, Exclude LLT1

- Beam event

  LLT1 Beam ON
  LLT2 At least 1 PDS
  HLT Mask in : LLT1 and 2

By using exclusion of triggers, we can negate any of the LLTs

Important!!!

High Level Triggers can be prescaled.

Putting it all together

Examples of what not to do

- *x* CRTs and *y* SSPs
  - Counting triggers not planned for the CRT
- A CRT and a SSP **OR** X CRTs and BI
  - Logic including both AND and OR in HTLs
  - Doing this using both LLTs and HLTs is possible
- Beam on, *x* SSPs *n* ns later and *y* SSPs *m* ns after that
  - Delays are applied at channel level (and are common to all triggers)
- Build a HLT from prescaled LLTs
  - Hard to evaluate efficiencies. Prescales only possible on HLTs

Trigger Priority List (personal view)

This is also likely to be the order they will be put in place on the CTB

1. Zero/Minimal bias triggers (commissioning of board and board reader)
2. CRT triggers (to use for commissioning before beam). Ignore beam instrumentation.
   - Front-to-back triggers (through-going muons)
   - Vertical muons (are there CRTs on top of cryostat?)
   - Stopped muons (fire one side of cryostat and not the other)
   - Muons through the APA (fire both sides but selecting specific panels to have guaranteed APA crossing)
3. Beam (un)correlated triggers
   - Beam spill (simplest trigger)
   - Beam and selection BI detectors (looking for specific beam composition)

$$\begin{aligned} e^- &\quad Chkv_1 \wedge Chkv_2 \\ \pi &\quad \neg Chkv_1 \wedge Chkv_2 \\ K/p &\quad \neg Chkv_1 \wedge \neg Chkv_2 \end{aligned}$$

4. Triggers with PDS
   - Mostly to study the PDS system in combination with other systems

Summary and Status

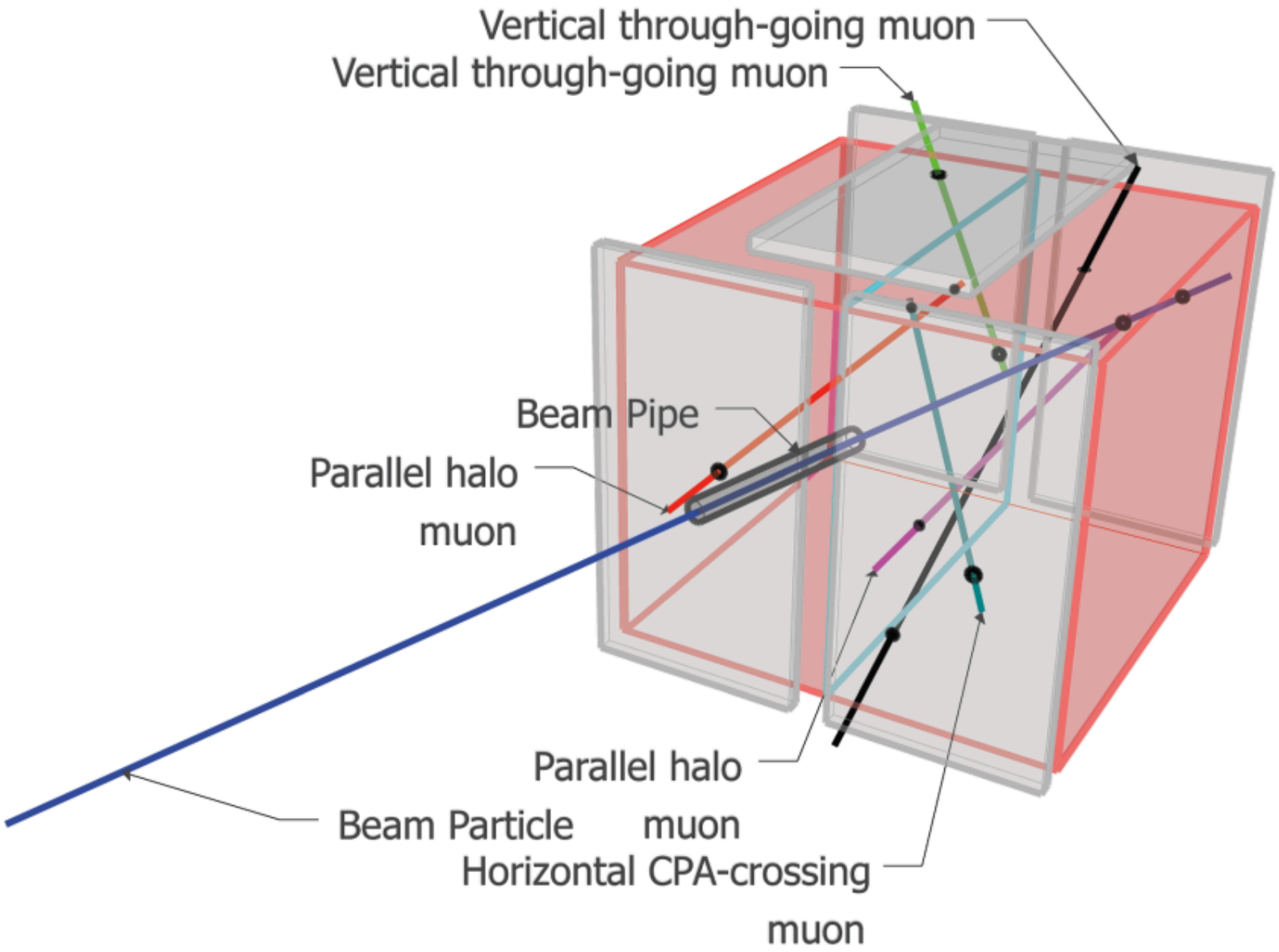
- The trigger is very flexible and allows to do almost anything
- Logic available is limited, so priorities have to be defined
- Plan is to put in as many triggers as requested, while logic is available
  - When we run out of logic, we'll need to start to prioritize
- CTB is in place and basic firmware is written
  - Planning to test some basic triggers next week (using controlled inputs)
  - Communication hurdles with timing system are now solved.
  - Focus on constructing triggers and commissioning
- Formal documentation detailing the trigger structure is being drafted

Call for feedback

Decisions are being made. Time for changes is limited, so any extra requests are **urgent** (and not guaranteed to be feasible).

Support Slides

CRT


Vertical through-going muon
Vertical through-going muon
Beam Pipe
Parallel halo muon
Parallel halo muon
Beam Particle
Horizontal CPA-crossing muon

Beam Instrumentation