# KLMTRG

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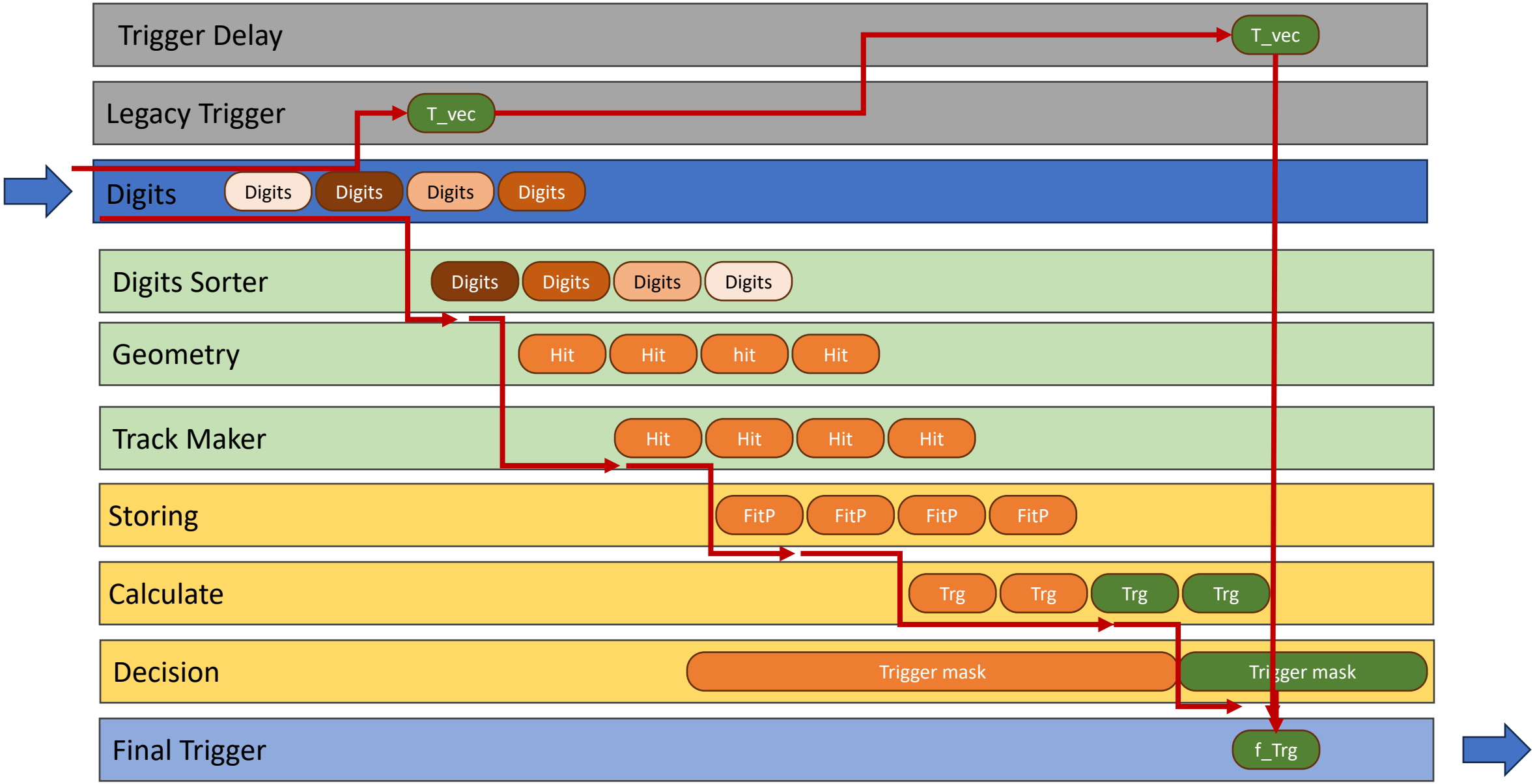
# Status

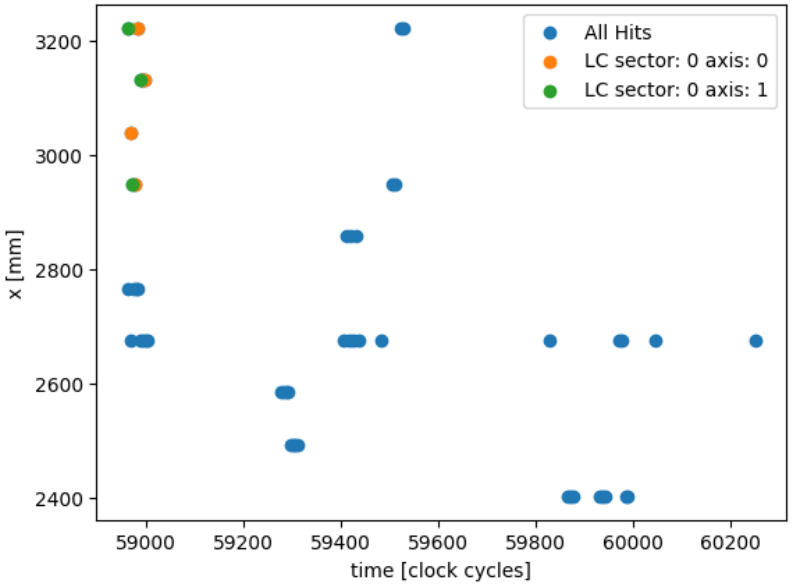
- The new KLMTRG Firmware has all core logic implemented and tested.
- Fine-tuning of register parameters is still needed.
- Several register parameters determine different aspects of trigger behavior.
- Not all parameters can be easily tested in simulation.
- For the next run period, it is important to test the new trigger with various parameters.
- Input from analysis groups is needed to provide feedback on the parameters.

# KLM Trigger

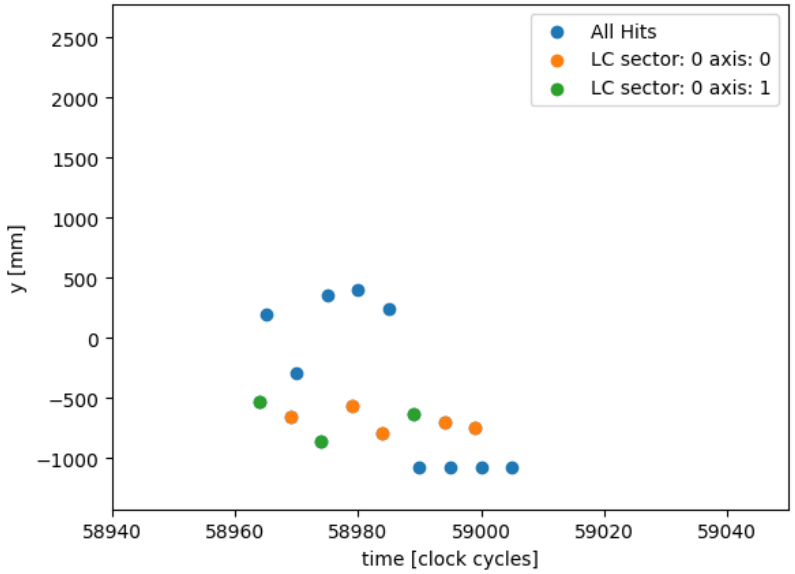

Trigger Delay
T_vec
Legacy Trigger
T_vec
Digits
Digits
Digits
Digits
Digits
Digits Sorter
Digits
Digits
Digits
Digits
Geometry
Hit
Hit
hit
Hit
Track Maker
Hit
Hit
Hit
Hit
Storing
FitP
FitP
FitP
FitP
Calculate
Trg
Trg
Trg
Trg
Decision
Trigger mask
Trigger mask
Final Trigger
f_Trg

# Trigger Chain

## Legacy Trigger




## Track Maker




Plot: Legacy Trigger

- Shows the data stream as it arrives on the UT3.
- X-axis represents arrival time in clock cycles.
  Y-axis represents the X coordinate (equivalent to the layer number).
- Illustrates how the legacy trigger looks for hits within a sector that span multiple layers.

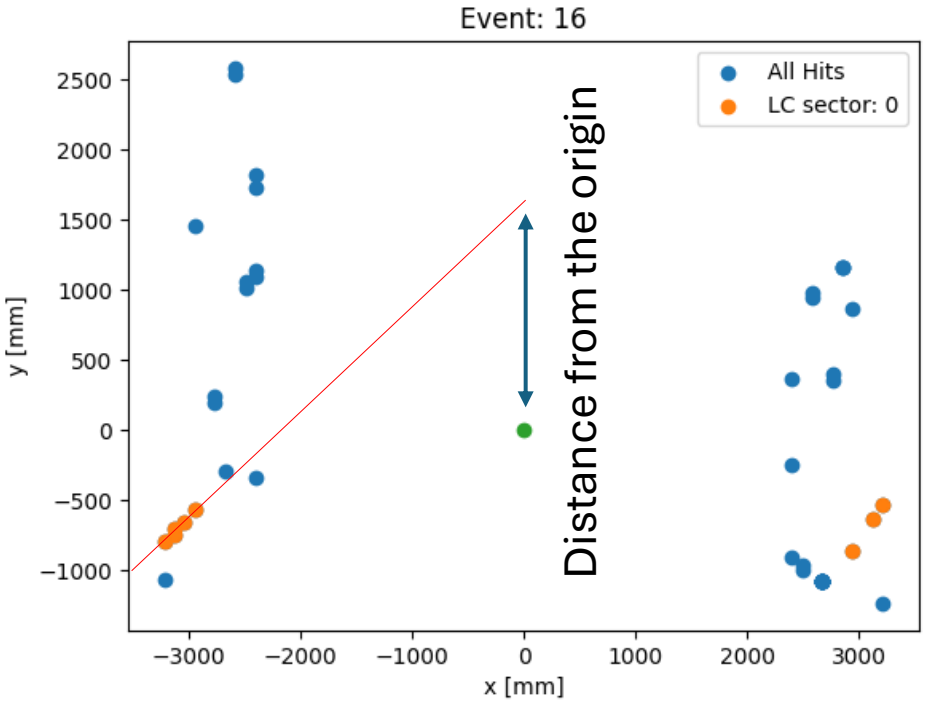
Plot: Track Maker

- Turns hits into tracks.
- X-axis: arrival time in clock cycles. Y-axis: Y coordinate.
- Each track stores the last hit and compares it to the current hit.
- If the current hit is within a given Y distance, it is added to the track.
- Visible gaps in Y distance between consecutive hits due to hits not being sorted by layer number.
- Sorting hits by layer number offers a significant advantage.

Plot: Track Fitter

- Shows how hits are combined into a single track.
- The track is fitted, and only the distance to the origin (at x=0) is calculated.
- If within a range controlled by a register, it either triggers or not.

## Track Fitter



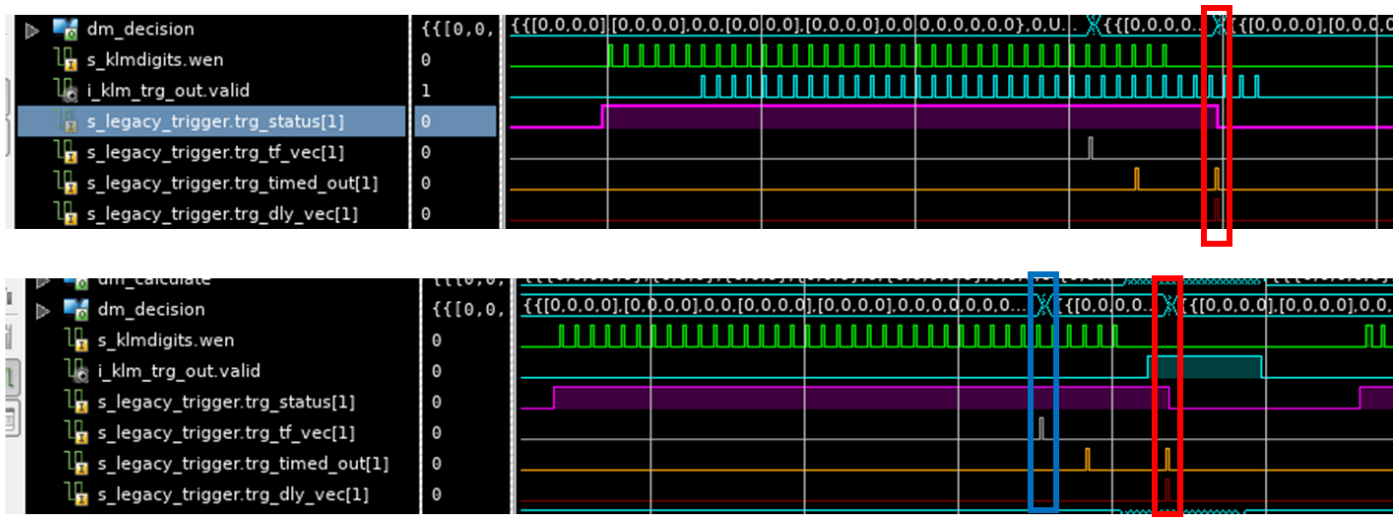
# Registers

| Module | Register Name | Description |
|---|---|---|
| track_finder | TRG_NLAYERS | How many layers need to have fired |
| TRIGGER_DELAY | trg_latency | Time Between the first hit and the final trigger decision |
| strip_mask | hit1d_in_data | Allows to veto individual strips (only effects SLF) |
| TrackMaker | Y_cutoff | Determines the maximal y distance between consecutive hits to be in the same track |
| data_stream_sorter | sorter_depth | How many hits the sorter can store before changing state to overflow and sending out DIGITS without sorting |
| calculate | Cutoff | Gives the maximum distance from the origin at which the track can pass the x = 0 line in order to be counted as a hit. |
| decision | trigger_mode | Determines if both planes are combined via a logical “OR” or a logical “AND” |
| decision | number_of_digits | Determines the minimal number of hits that need to be in a track to be used. Tracks with less hits are ignored |
| decision | max_number_of_digits | If a track has more than this amount of hits the module goes into overflow state. In this state the SLF trigger is identical to the LC trigger |

# Digits Sorter

- Registers: use_sorter, sorter_depth
- use_sorter:
  - If set to 0, the sorter is completely bypassed.
  - If set to 1, the sorter is used.
- **sorter_depth:**
  - Determines how many events can be stored in the sorter before overflow handling and sending starts.
- Normal operation:
  - The sorter waits for the immediate trigger from the Legacy trigger.
  - Events are sent in a sorted manner after receiving the trigger.
- Overflow condition:
  - If an event is very long, the sorter allows for early sending of events to prevent overflow.

# Digits Sorter




With sorting



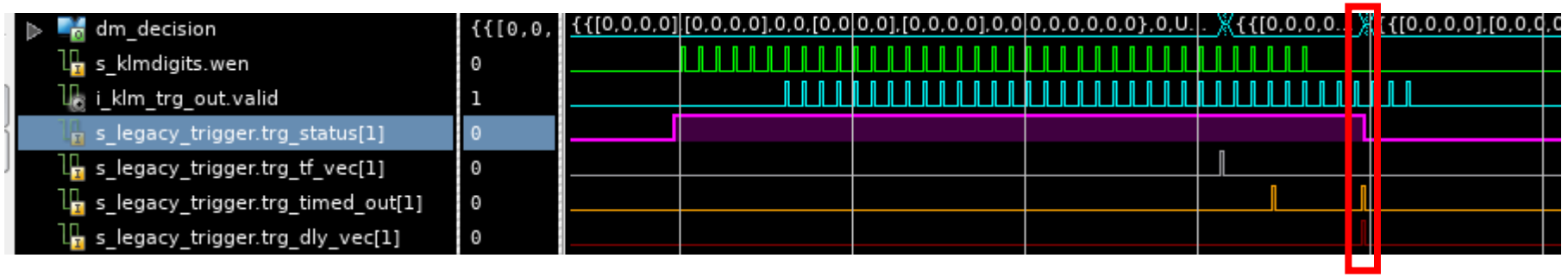

- The BASF2 event generator produces events that differ from those observed by the detector.
- The new firmware (FW) includes an option to record KLMDIGITS as they arrive at the UT3.
- These recorded events are typically short, with around 10–20 hits per burst.
- In contrast, events generated by the Event generator contain 50+ hits per event.

- The picture shows the operations of the digit_sorter.
- It is clearly visible that:
  - Input digits are spaced apart.
  - Output digits form a continuous block.
- A redesign was necessary because:
  - The digit sorter, during normal operations, only sends data after all hits are registered.
  - This reduces the available processing time by half.
  - For long events, the remaining processing time is reduced even further.
- An overflow mechanism is necessary to allow data to be sent before the normal operation finishes.
- All modules downstream of the digit sorter required reworking to support pipelined operation.

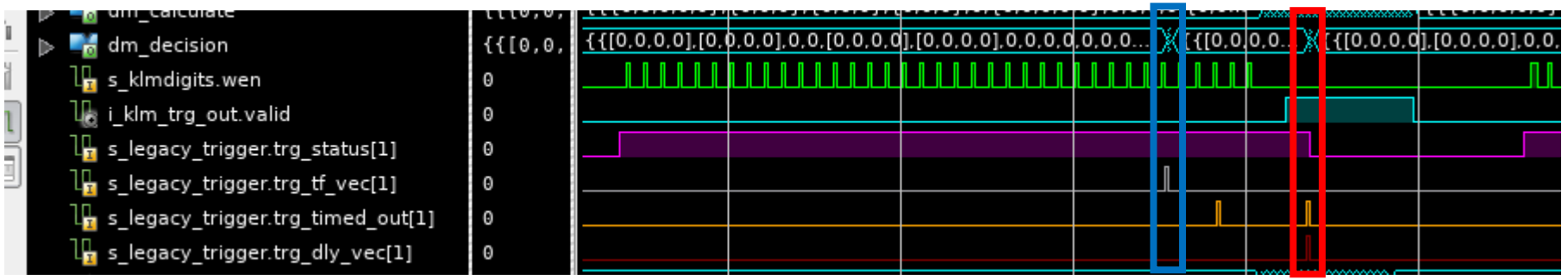
# Processing Pipeline

- Per sector it takes 3 clock cycles to receive a new KLM Digit
- That means 3 sectors can fire at the same time without causing any pile up

Without sorting




With sorting



# Geometry

- The geometry converter consists of two completely independent implementations:
  - One for EKLM
  - One for BKLM
- BKLM:
  - More complicated geometry structure
  - Requires storing **geometry parameters for each sector, layer, and axis**
  - Geometry data is stored in a RAM module
  - Takes two clock cycles to load data from the RAM module
  - Latest version pipelines all RAM reads, eliminating wasted clock cycles during data fetching
  - The geometry file used for BKLM geometry conversion has been updated to incorporate the latest information from BASF2.
- EKLM:
  - Simpler geometry structure
  - One set of **geometry parameters is used for all sectors, layers, and axes**

# Track Maker

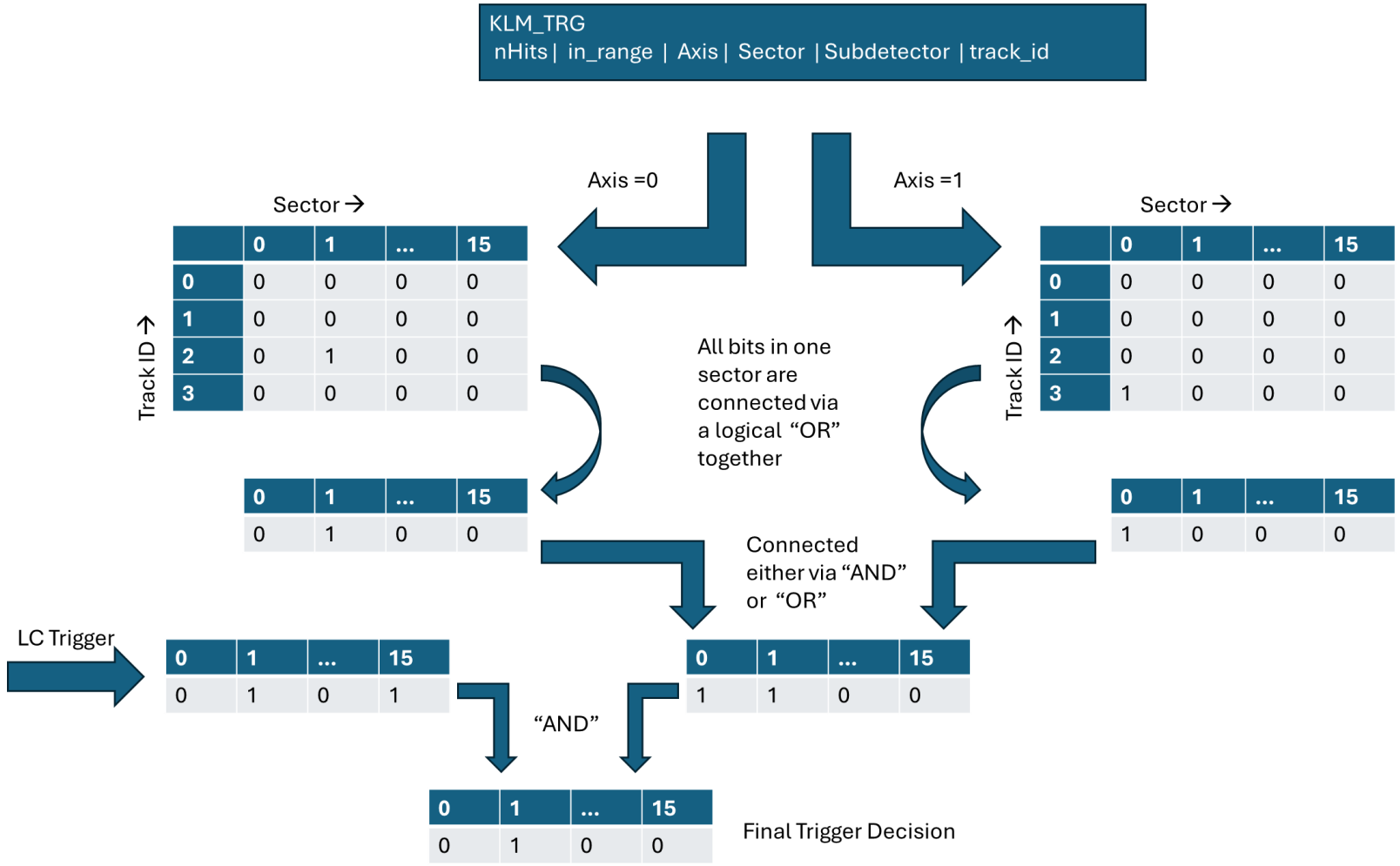
- The Track Finder separates hits into individual tracks based on the Y distance.
- It currently supports up to 4 tracks per sector.
- The Y position of the last hit in each track is stored and compared to the current hit.
- If the Y position of the current hit is within a distance (**controlled by a register value**), it is added to the track.
- From all available tracks, the one with the least Y distance is selected.
- The module benefits significantly from the digit sorter.
- Originally, the module faced timing issues, making it difficult for ISE to meet requirements.
- It has been redesigned. Now it only allows up to 7 sectors to have events simultaneously. This and other tweaks have resolved the timing issues.

# Storing

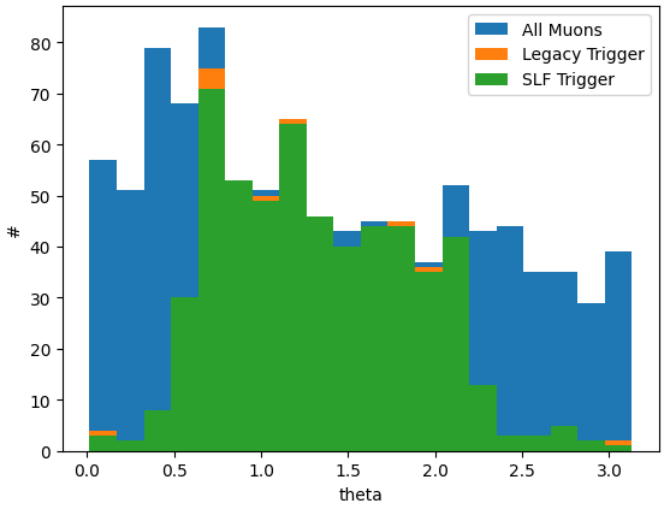
- The storing module creates and stores coordinate sums for the fit calculation.
- **It does not use any registers**.
- The sums are reset on a per-sector basis, depending on the status of the legacy trigger module.
- Redesigned to support pipeline operations, now includes a RAM block for simultaneous reading and writing.
- Optimization was required so that data written to the RAM block is available immediately after being written.
- The data is cached, allowing it to be accessible in the next clock cycle for the reader.

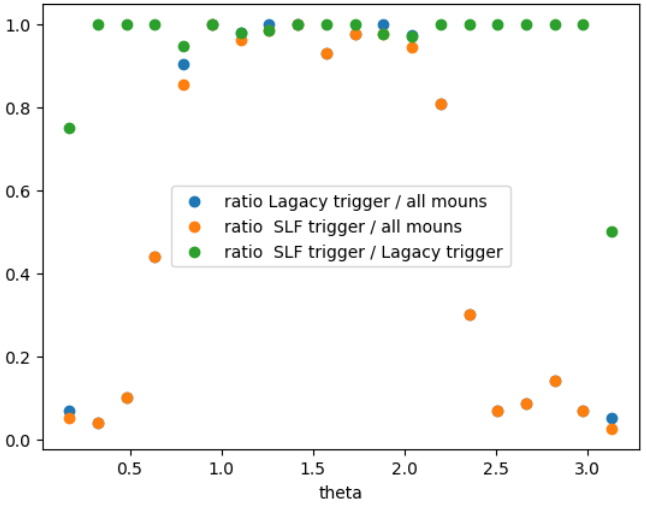
# Decision Maker

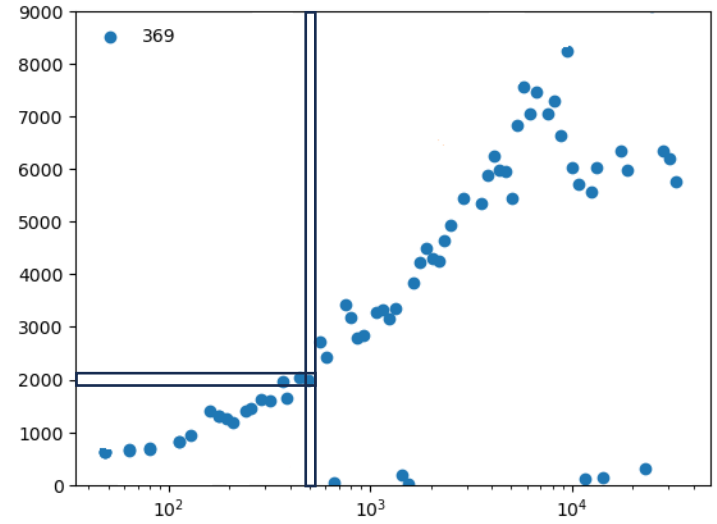
- The Decision Maker receives trigger information from the "calculation module.“
- This information is stored in the sector/track ID matrix.
- All sectors (columns) in the matrix are connected via a logical OR.
- Depending on **register** settings, the bit vectors of the two planes are connected either with a logical OR or a logical AND.
- Once the Legacy trigger arrives, it is connected to the SLF trigger vector using a logical AND.
- The Decision Maker includes two extra conditions:
  - Each track must have a minimum number of hits to be used, controlled via a **register**. If not met, the track is ignored.
  - A **register** sets the maximum number of tracks, allowing control over the maximum number of hits per track.
- If the number of hits exceeds the maximum limit, the Decision Maker forwards the Legacy trigger as the output SLF trigger.



# Simulation Results




- This simulation uses a data set generated by the KKMC generator, containing 1000 events.
- KLMDIGITS are extracted from the data set and fed into the VHDL KLMTRG firmware simulation.
- The simulation follows the normal data path, and the output is compared to the MCParticle data to generate the plots shown.
- Top left plot:
  - Shows the muon distribution with respect to the angle theta.
  - Displays the distribution of muons that lead to a Legacy trigger and those that lead to an SLF trigger.
  - The Legacy and SLF trigger distributions are very similar.
- Bottom left plot:
  - Displays the ratios of muons with Legacy triggers over all muons, SLF muons over all muons, and SLF muons over the Legacy trigger muons.
  - It is clearly visible that, with the current SLF cutoff parameter, the loss of muons is negligible.
- Right plot:
  - Shows the trigger rate as a function of the SLF cutoff parameter.
  - With the 500 mm cutoff used in this simulation, the trigger rate is reduced by half.

# Summary

- The firmware is in a stable condition.
- Core logic has been implemented and tested in simulation.
- Simulations were conducted using both Monte Carlo-generated events and KLMDIGITS recorded directly on the UT3.Significant effort was made to address the issue of barely meeting timing.
- Now, the firmware consistently meets timing without issues.
- The next step is to test the firmware in actual operations.
- SLF trigger bits are sent to the GDL and GRL to be included in the trigger data stream.