ATLAS EXPERIMENT

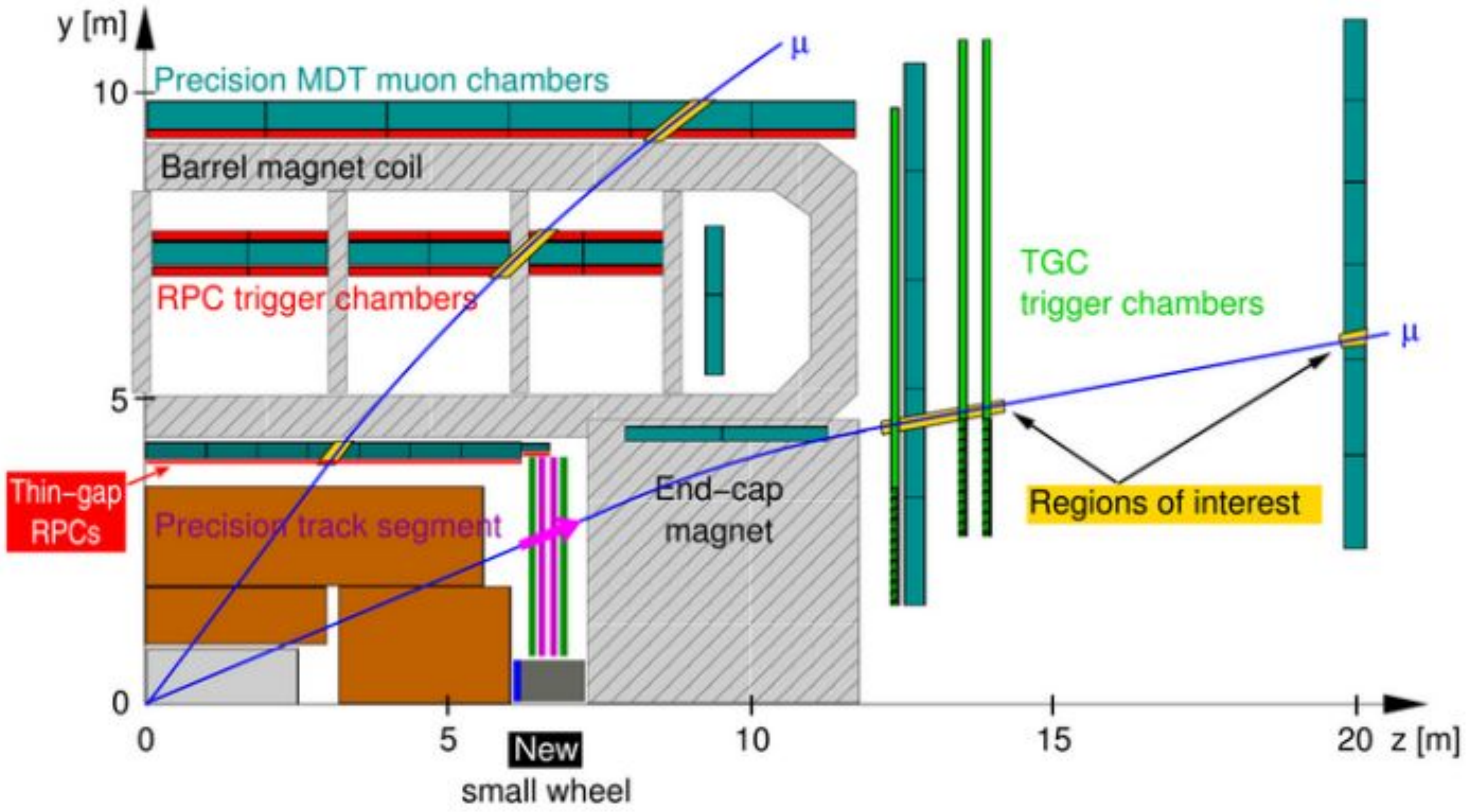
MAX-PLANCK-INSTITUT FÜR PHYSIK

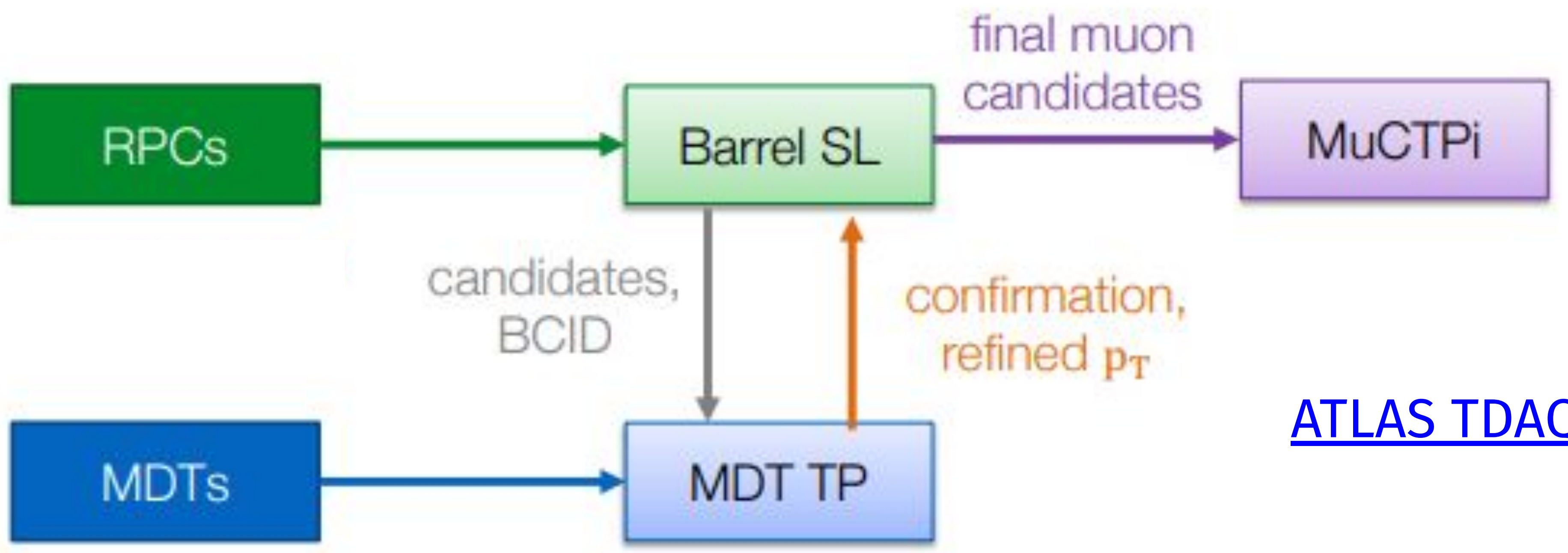
A Standalone Monitored Drift-Tube Trigger for the ATLAS HL-LHC Upgrade

D. Cieri on behalf of the ATLAS TDAQ Collaboration

29. October 2024 - 2024 IEEE NSS MIC RTSD - Tampa, Florida, USA

Baseline ATLAS L0 Muon Trigger Upgrade



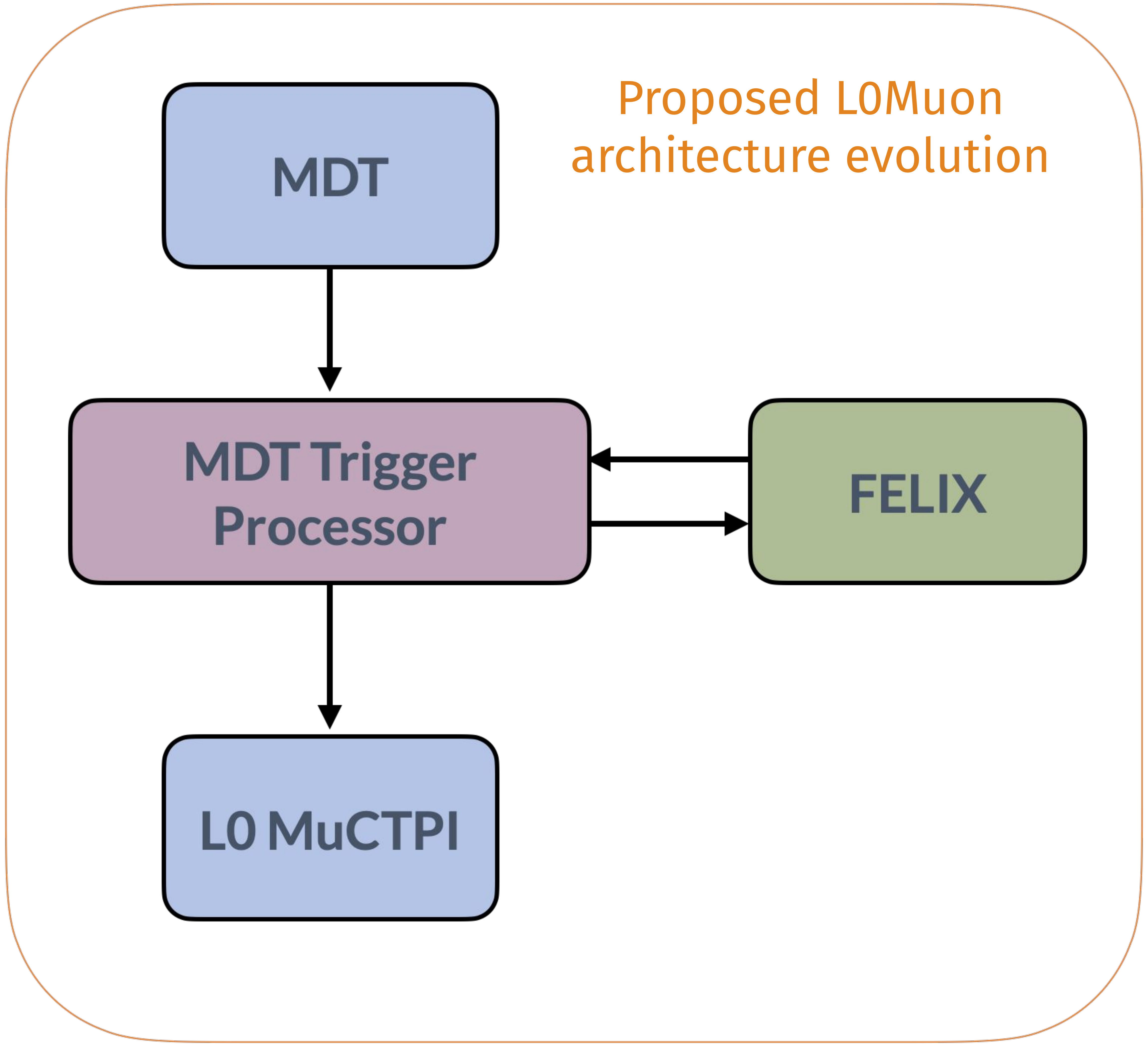


ATLAS TDAQ TDR

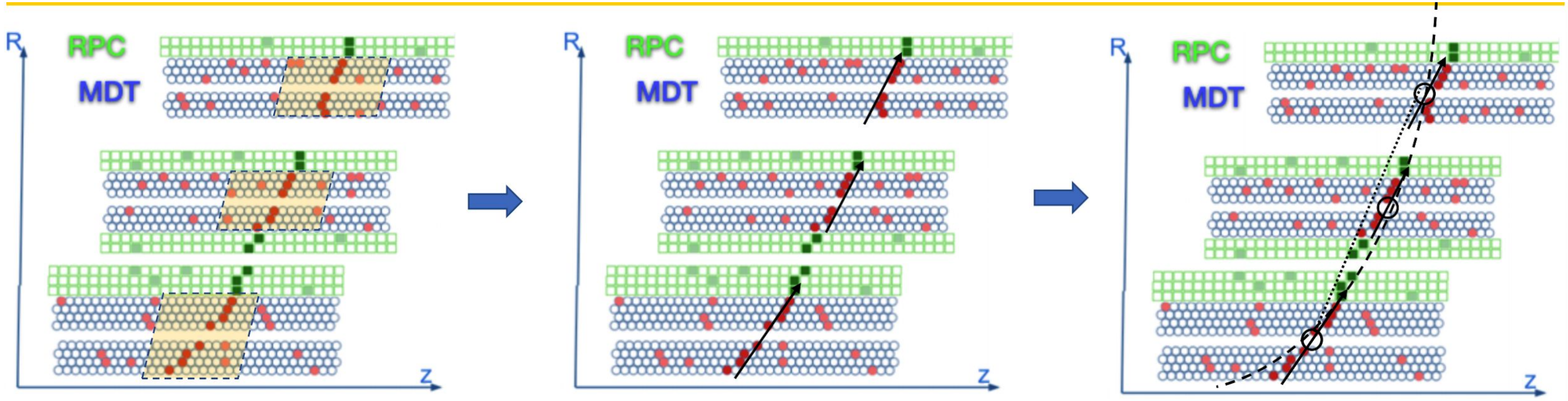
- Upgrade Goals:
  - unprescaled 20 GeV single muon trigger and an unprescaled low-p_T threshold dimuon trigger
  - Improve momentum resolution, maintain high efficiency, suppress fake rate
- Baseline L0Muon trigger consists of two subsystems
  - **Sector Logic** (**SL**) reconstructs muon tracks using data from the fast trigger chambers (**RPCs, TGCs**)
  - Monitored Drift Tube Trigger Processor (**MDTTP**) refines muon track p_T using for the **first time** data from the precise **MDT** chambers

Motivation for a standalone trigger

- RPC performance degradation expected for already operational chambers in ATLAS (Middle and Outer layer)
- Baseline MDT trigger already accounts for some possible inefficiencies by considering a loosened coincidence
- A “standalone” MDT trigger can be designed to avoid completely dependency on RPCs
  - Concept could also be applied to FCC experiments



Baseline MDT Trigger Algorithm



Hit Extraction

- Reconstruct SL vectors per MDT station
- Match the MDT hits to SL input in space and time

Segment Finding

- Reconstruct segments in the different MDT stations using the matched MDT hits

pT estimation

- Calculate the muon candidate pT by estimating the deflection between the segments due to the B-field

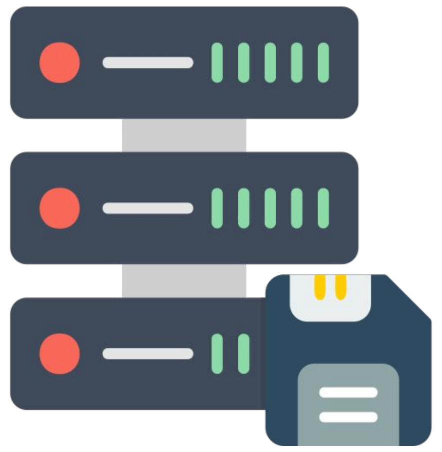
The Challenges

1. Bunch Crossing Identification

Without RPC's information, the collision time must be identified using MDT data.

2. Region-of-Interest

No RPC to filter MDT hits in space. Pattern recognition should happen in the entire MDT chamber.



3. Trigger Rate and Latency

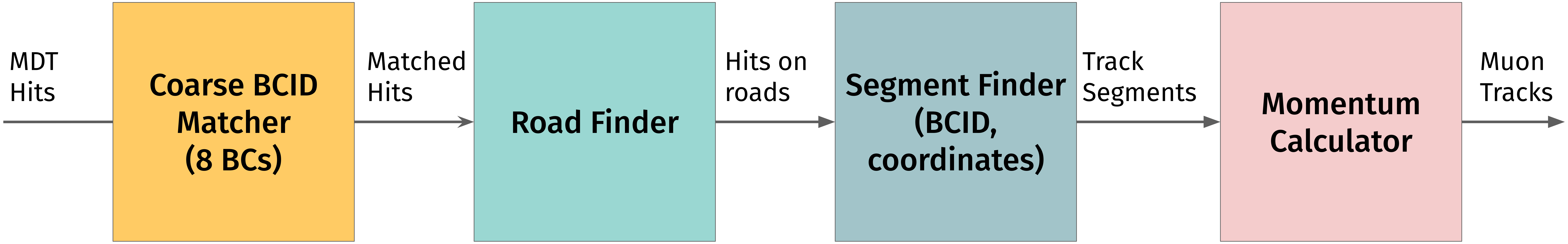
Standalone trigger should reduce trigger rate from 40 MHz to ~40 kHz, with a limited latency budget (~2 μs).

4. Efficiency

Standalone MDT trigger should reject bad coincidences, while keeping a high efficiency around the 20 GeV threshold.

The Design

- (Very) preliminary FPGA architecture for the standalone trigger design
  - Efficiency and rate performance to be studied
  - Idea is to estimate resource usage, to see if it could fit in current system
    - Virtex Ultrascale+ VU13P on MDT Trigger Processor
- Concept applied to a large MDT sector, but can be tuned for all sectors



The Design

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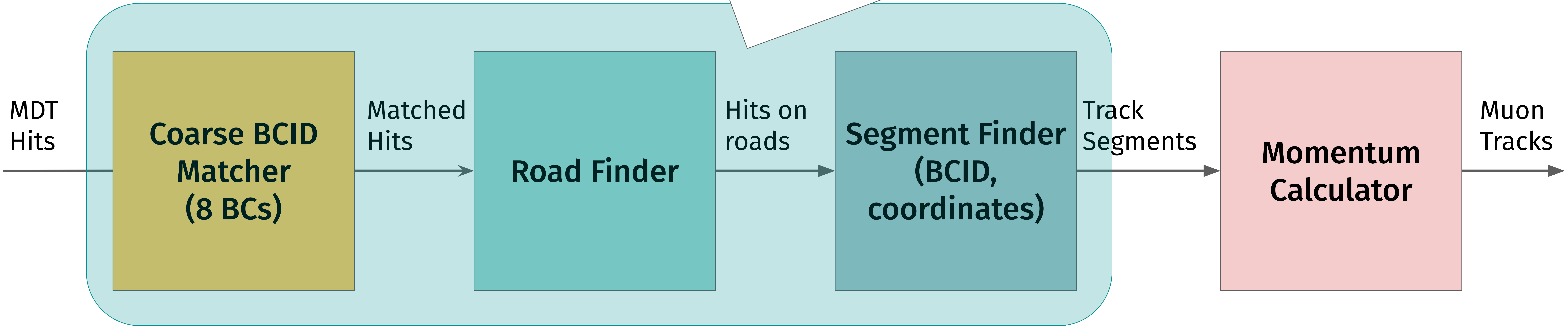
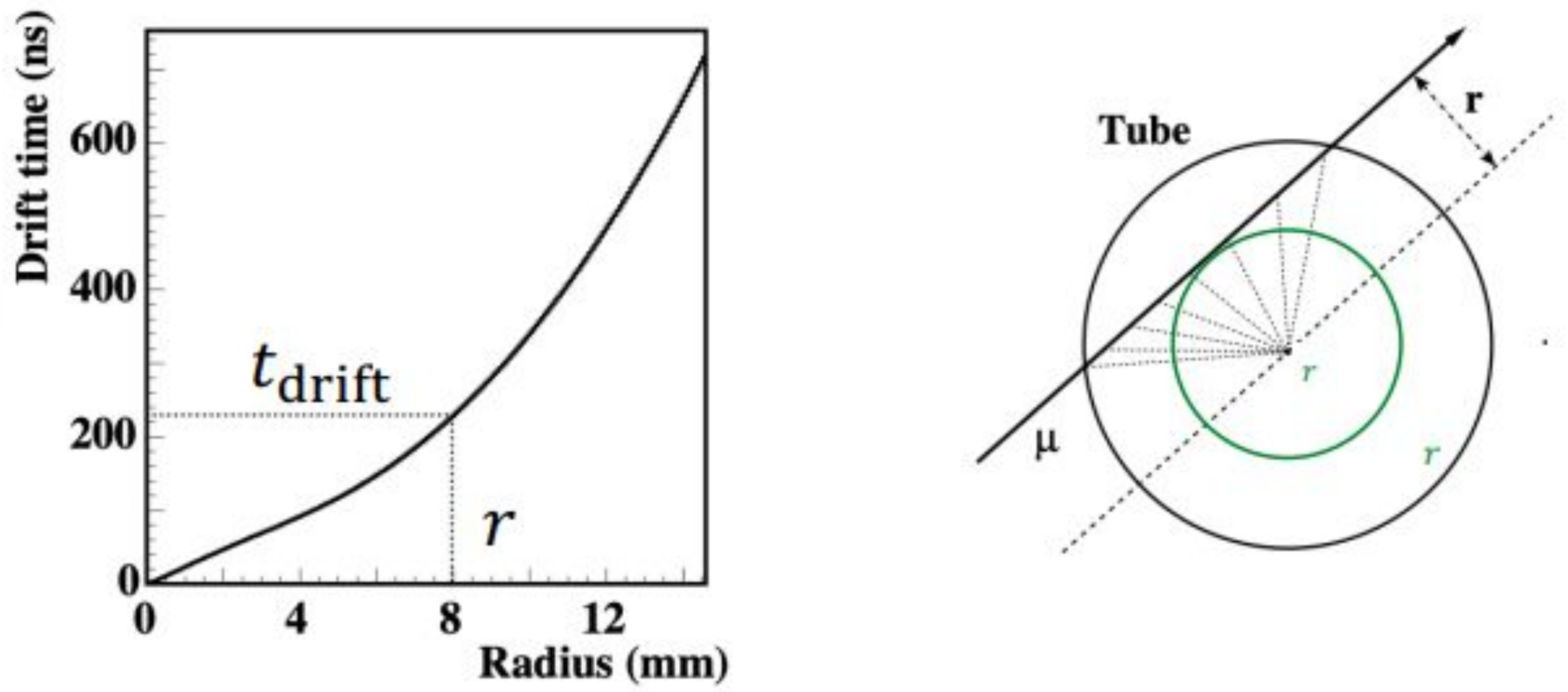
- Concept applied to a large MDT secto ectors

New Firmware Blocks, replacing RPC functionalities

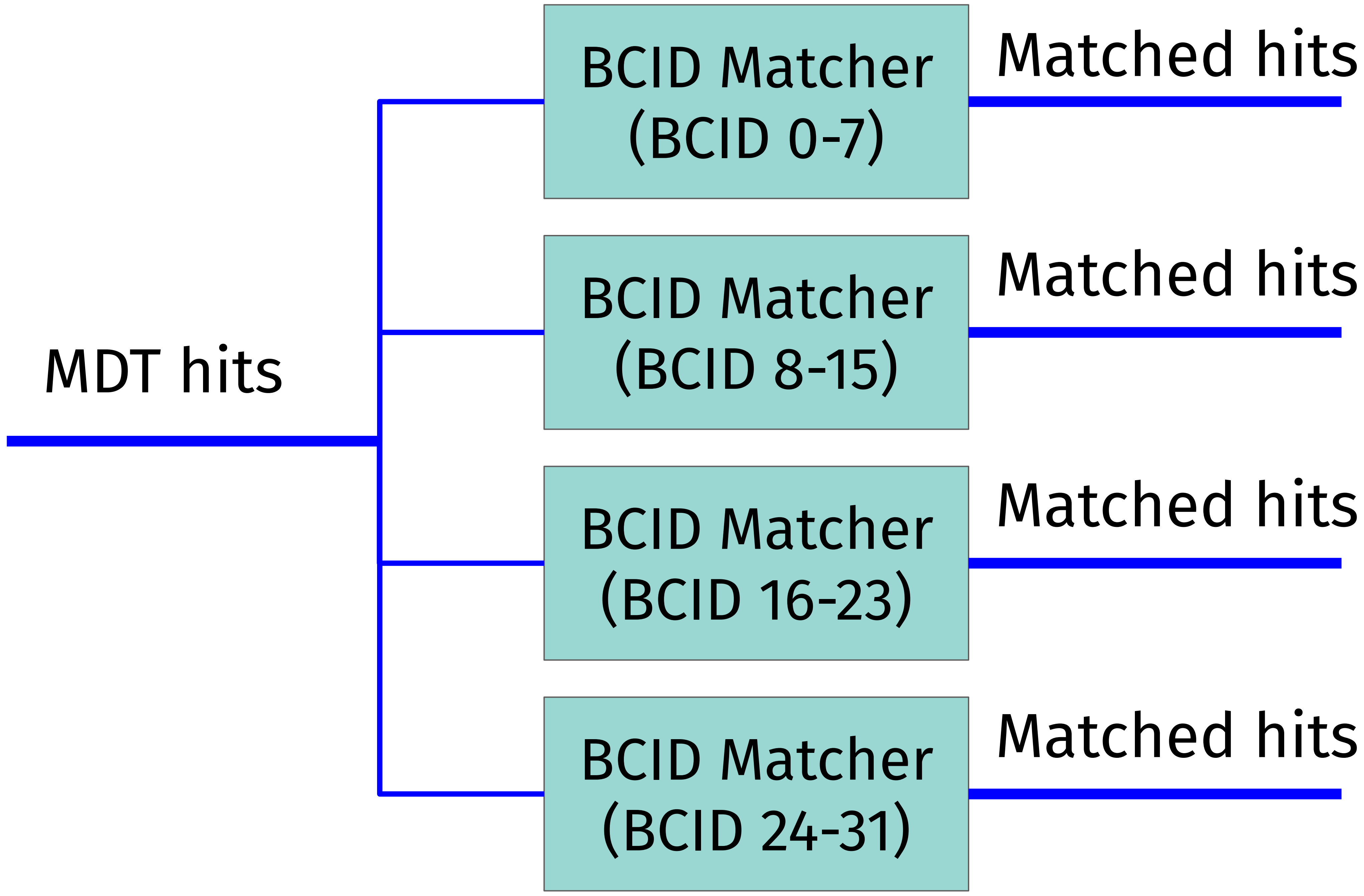


Coarse BCID Matching

$t_{drift} = t_{hit} - t_{BC} - t_{offset}$



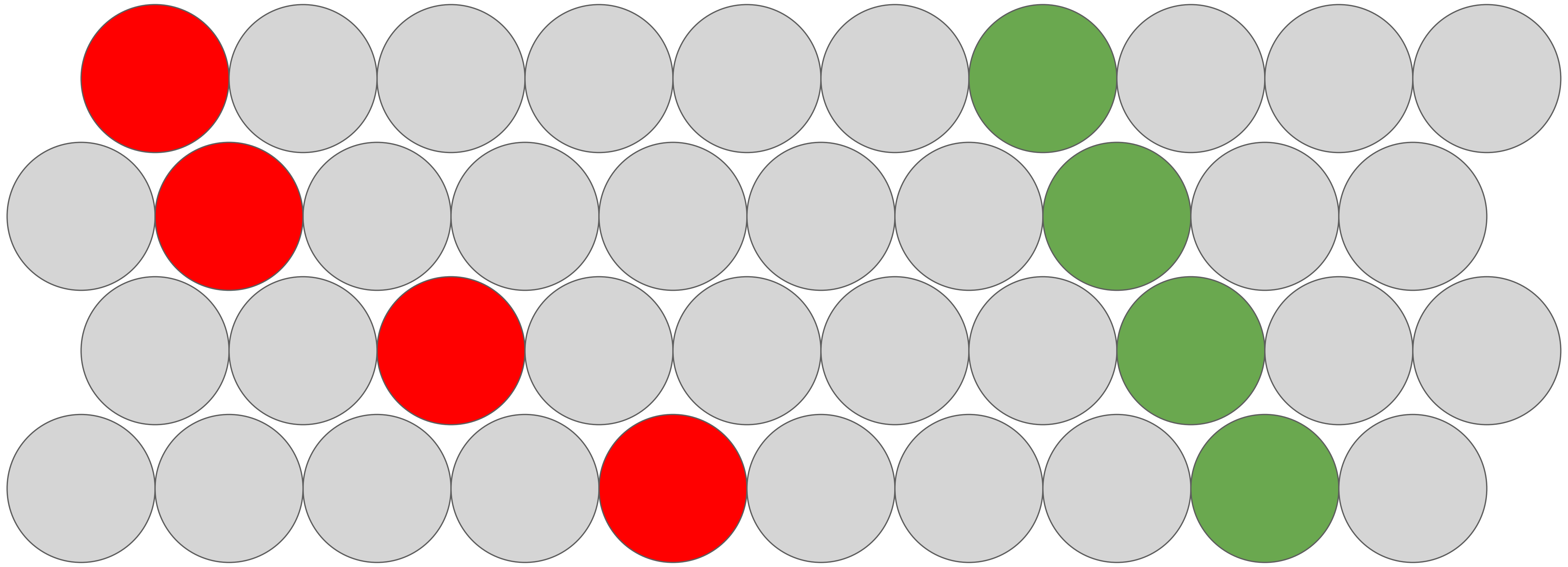
A radius-time RT relation then allows us to obtain a drift circle



t_{drift}: drift time, **t_{hit}**: hit time from MDT tube, **t_{BC}**: collision time, **t_{offset}**: individual tube constants

- Knowledge of t_{BC} fundamental to measure drift radius, and exact hit position
- Each MDT hit is compatible with 32 possible bunch crossings
- Maximum drift time 800 ns, LHC bunch crossing period 25 ns
- MDT Hits are sent to four BCID Matching blocks, that checks compatibility with a group of eight bunch crossings
  - t_{drift} should be in range [0 ns, 800 ns] for at least one t_{BC} in the group

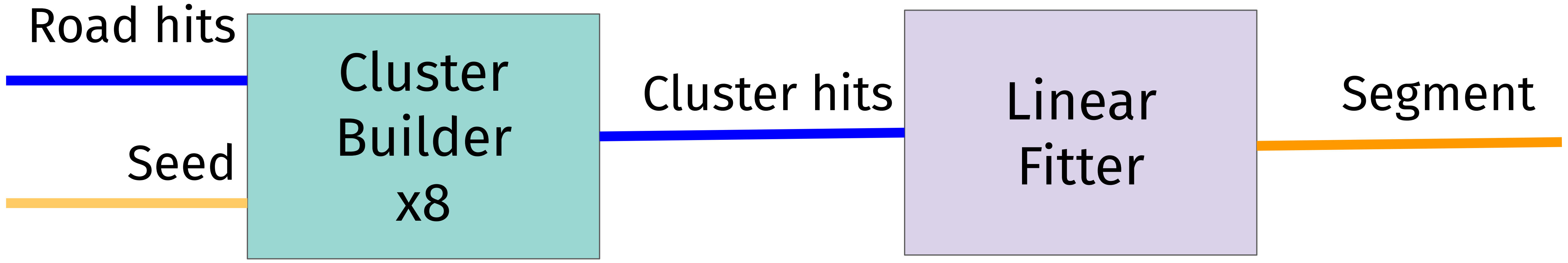
Road Finder

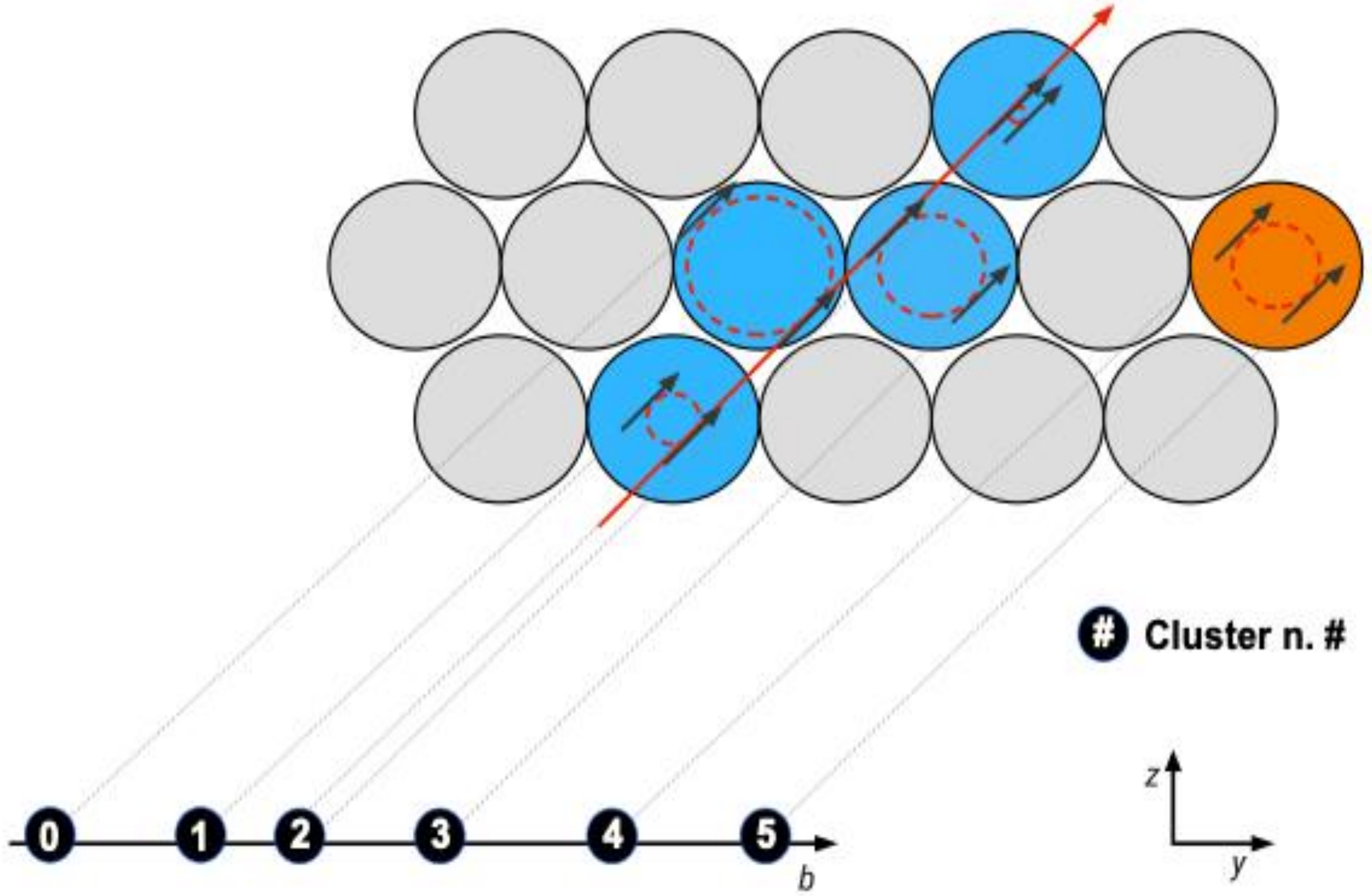


Valid Road
Not Valid Road

- Road: pre-defined set of MDT tubes compatible with a high-p_T muon track
- MDT hits compatible with a bunch crossing group are matched to the roads in the chambers
  - A limit of 16 active roads per chamber is set
- The road with the highest hit content is eventually selected, and the tube coordinates are then used to extract the seed track parameters (angle, position), using a linear regression fit
- This process is done independently for each MDT chamber and station (6x3)

Segment Finder





$$b_{\pm} = \pm\sqrt{1 + m_{seed}^2} * r_{drift} - (m * y - z)$$

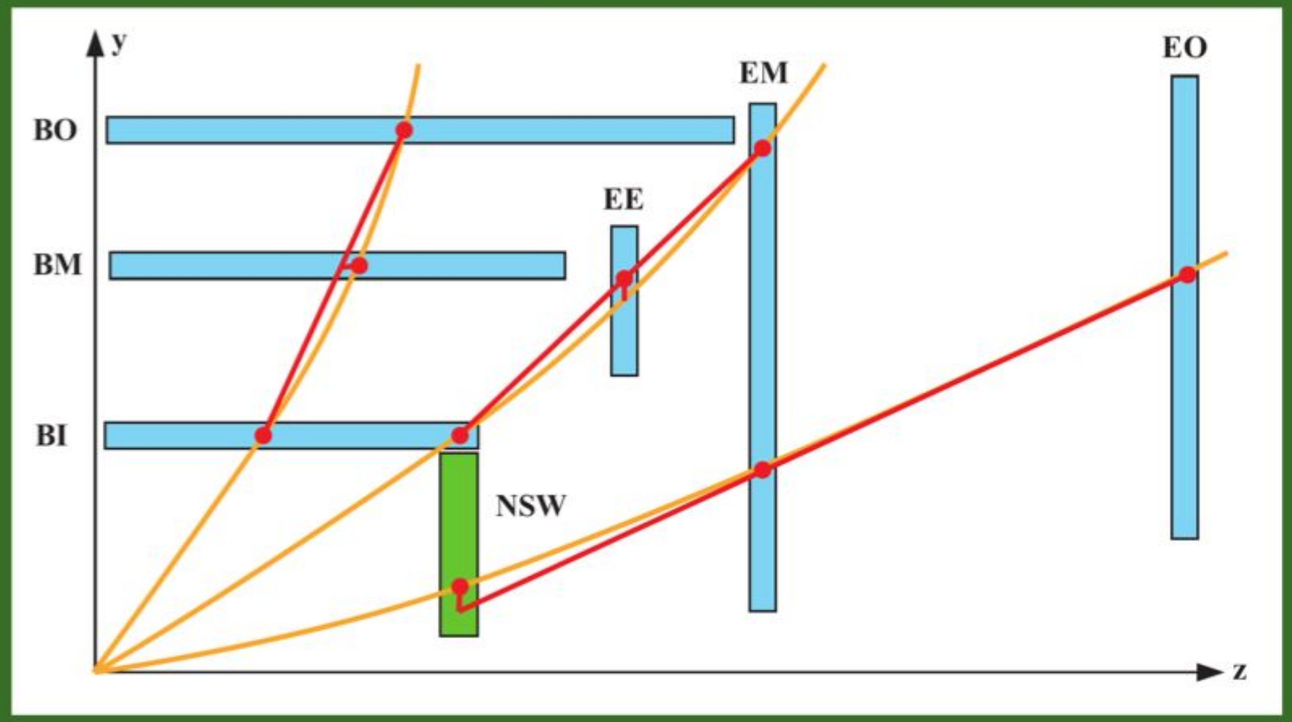
- Segment Finder reconstructs track segments using hits on roads and the just calculated seed angle
- Eight possible drift radii can be calculated for each hit -> Eight different segment finders (one for each t_{BC})
- Segment Finder builds hit clusters along the *y* axis, using the two possible hit positions $b_{\pm}$ (two-fold ambiguity)
- Cluster with the highest hit content and lowest χ^2 identifies segment and collision time t_{BC}
- Hits in cluster fitted to measure segment parameters (angle, position)

p_T estimation

- *Momentum Calculator* block same as baseline trigger
- Muon $\mathbf{p_T}$ is calculated using the reconstructed **MDT segment** coordinates
- Depending on the number of stations with valid MDT segments, muon p_T can be estimated as a function of the **sagitta *s*** or the **deflection angle *Δβ***
- **Φ, η corrections** take into account variations in the magnetic field
  - No Φ coordinate with current MDT front end electronics

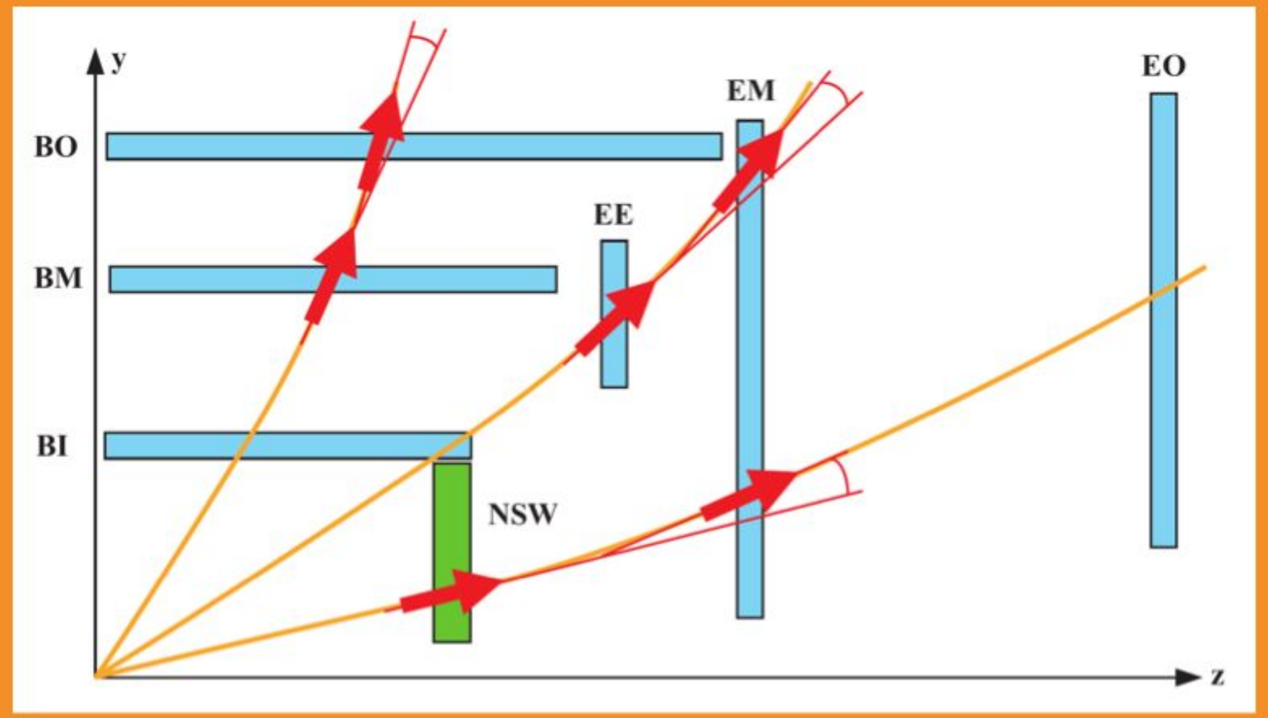
Sagitta Method

$$p_T = \Sigma_{i=0}^{2} \frac{a^i}{s^i} + \Sigma_{i=0}^{2} b_i \cdot \phi^i + \Sigma_{i=0}^{1} c_i \cdot \eta^i$$

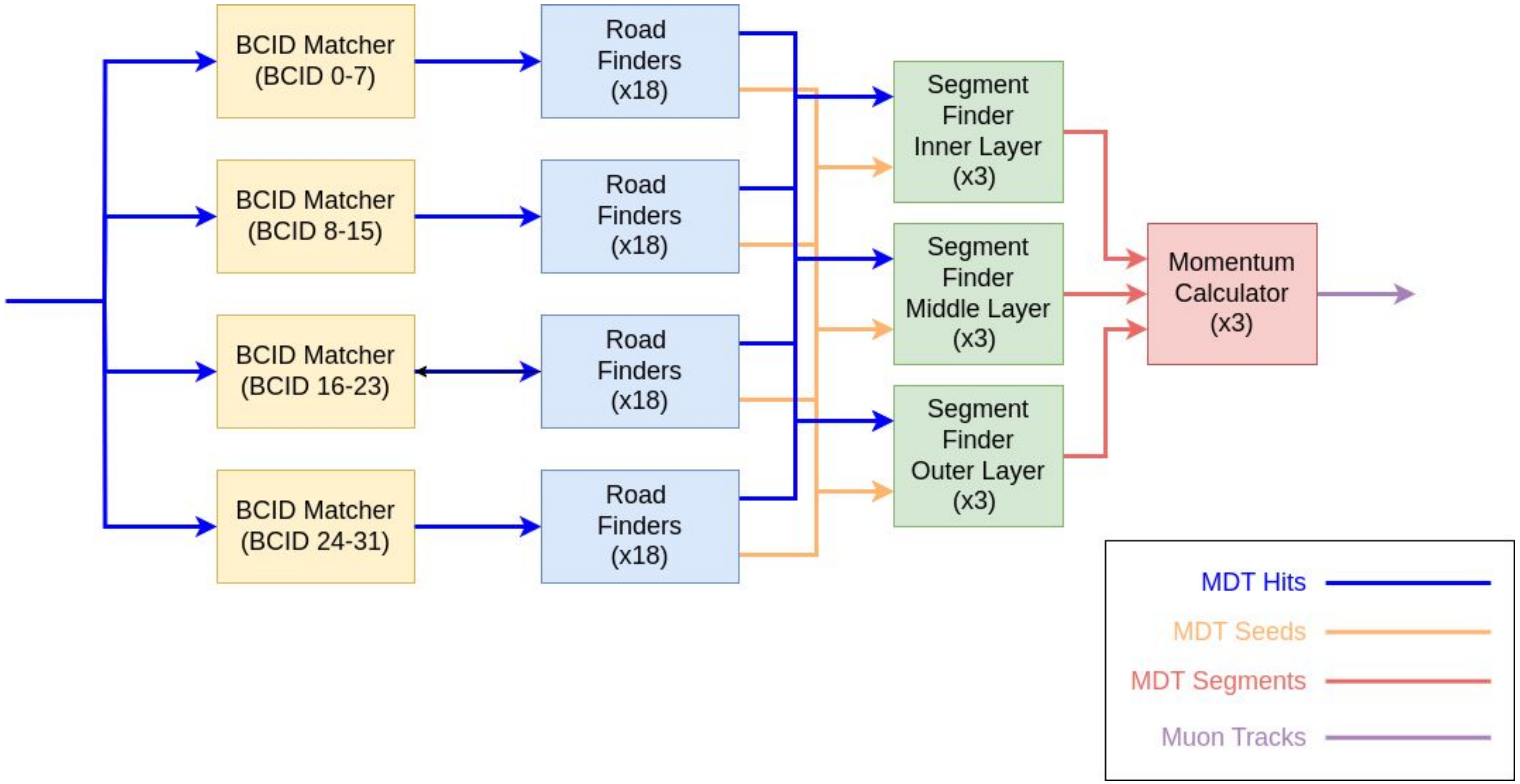


Δβ Method

$$p_T = \Sigma_{i=0}^{2} \frac{a^i}{\Delta\beta^i} + \Sigma_{i=0}^{2} b_i \cdot \phi^i + \Sigma_{i=0}^{1} c_i \cdot \eta^i$$



Firmware Implementation



- Standalone MDT algorithm implemented in VHDL targeting Xilinx VU13P FPGA (as in the MDT Trigger Processor)
- N. *Road Finders* per BCID group is equal to total number of chambers in sector (18)
- N. *Segment Finders* per station and N. of *Momentum Calculators* equal to max. number of tracks that can be reconstructed per BCID group (3, configurable)
    - Segment Finder + Momentum Calculator requires less than 200 ns -> Same blocks for all BCID groups

FPGA Implementation

- First implementation fits well (~37% LUTs) on the FPGA available on the MDTTP (AMD VU13P)
  - Resources of common blocks with baseline algorithm
  - Higher than baseline MDT Trigger (~20%), but still space for improvements
  - Half of logic used for road finder modules
- Total latency (First MDT hit coming in - Muon Track coming out) well within allocated budget of 2.0 µs
  - Faster than baseline 1.0 µs vs 1.6 µs
  - Baseline “slower” due to waiting time for SL candidate

Firmware	LUTs	FFs	DSPs	BRAM	URAM
Baseline	21 %	13%	5%	8%	11%
Standalone	37%	14%	14%	20%	8%

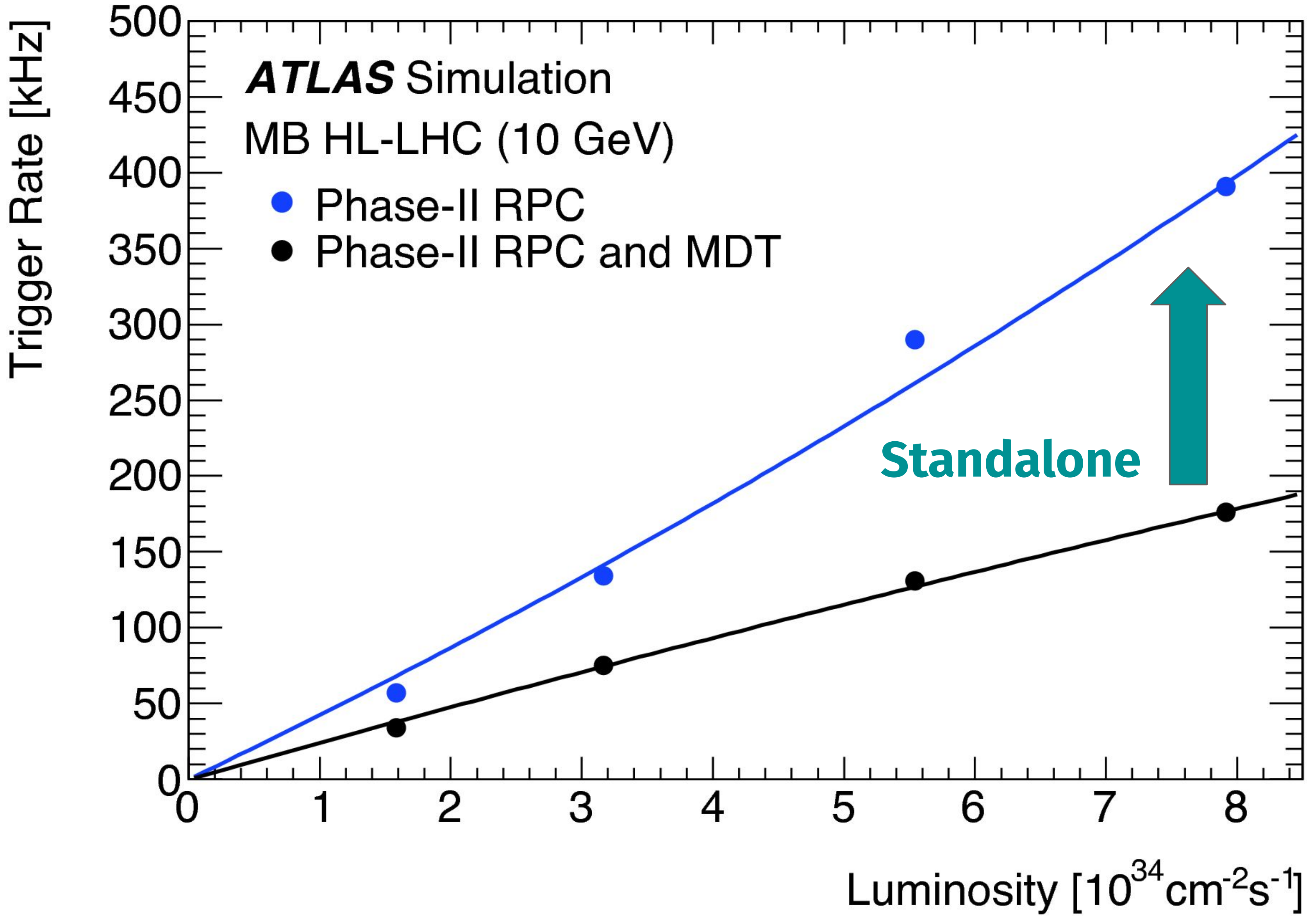
Resource Usage

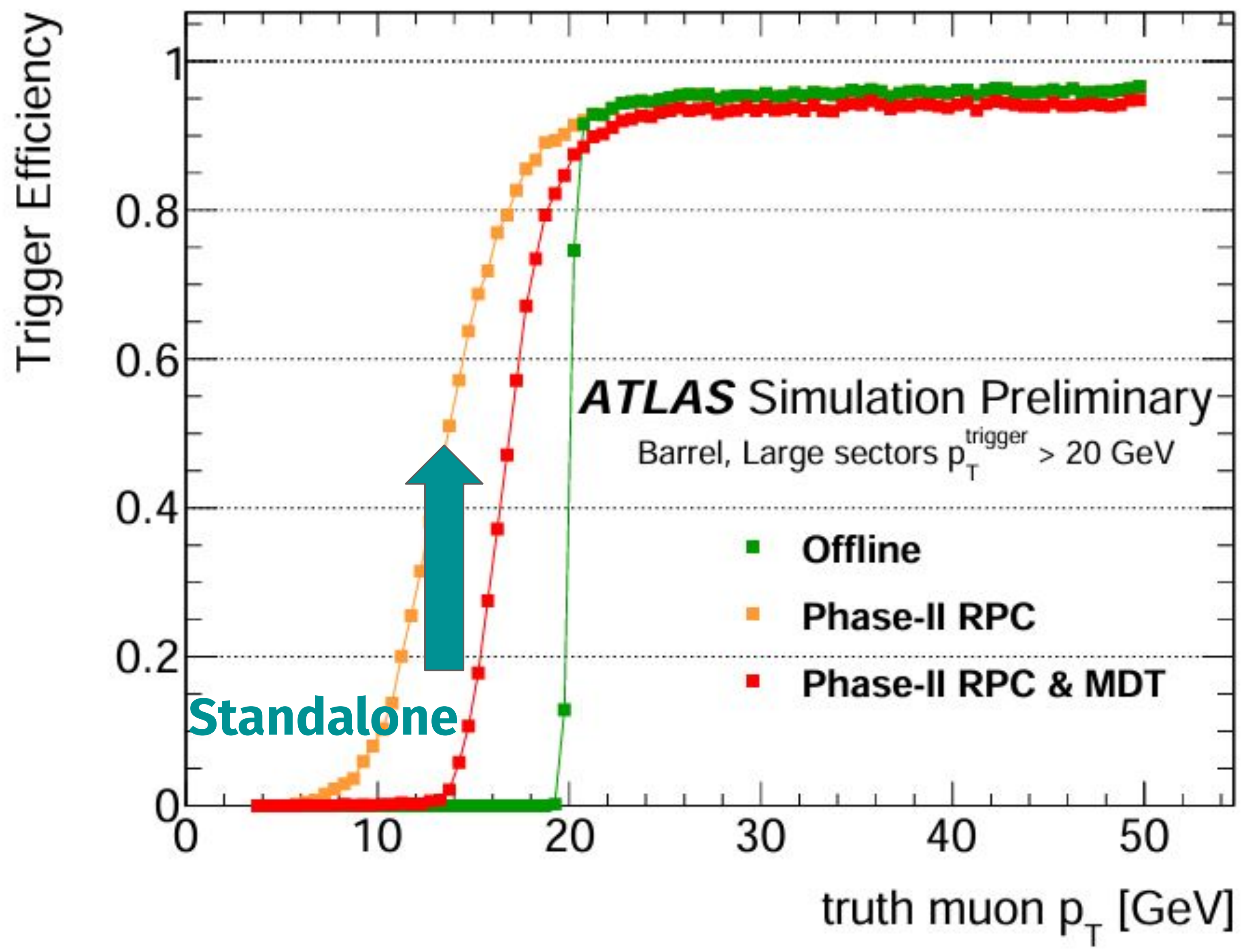
Firmware	Clocks @ 320 MHz	Latency (ns)
Baseline	526	1646
Standalone	324	1013

Latency

Standalone Trigger Performance

- MDT trigger without phi measurement (2nd coordinate) has degraded performance
  - Main impact on momentum resolution, worse by a factor 3-5 with respect to baseline
  - Substantial increases in rate expected (order 100kHz)
  - No effect on efficiency, but more low-pt muons accepted
  - Concept can be applied only to problematic regions without large increase in rate





Conclusions

Developed of a proposal for a standalone drift-tube trigger for the ATLAS HL-LHC upgrade. Design compatible with current hardware, requiring small change to L0Muon architecture.

Absence of Φ coordinate translates into degraded trigger performance. Design could anyway be applied to problematic regions to recover efficiencies.

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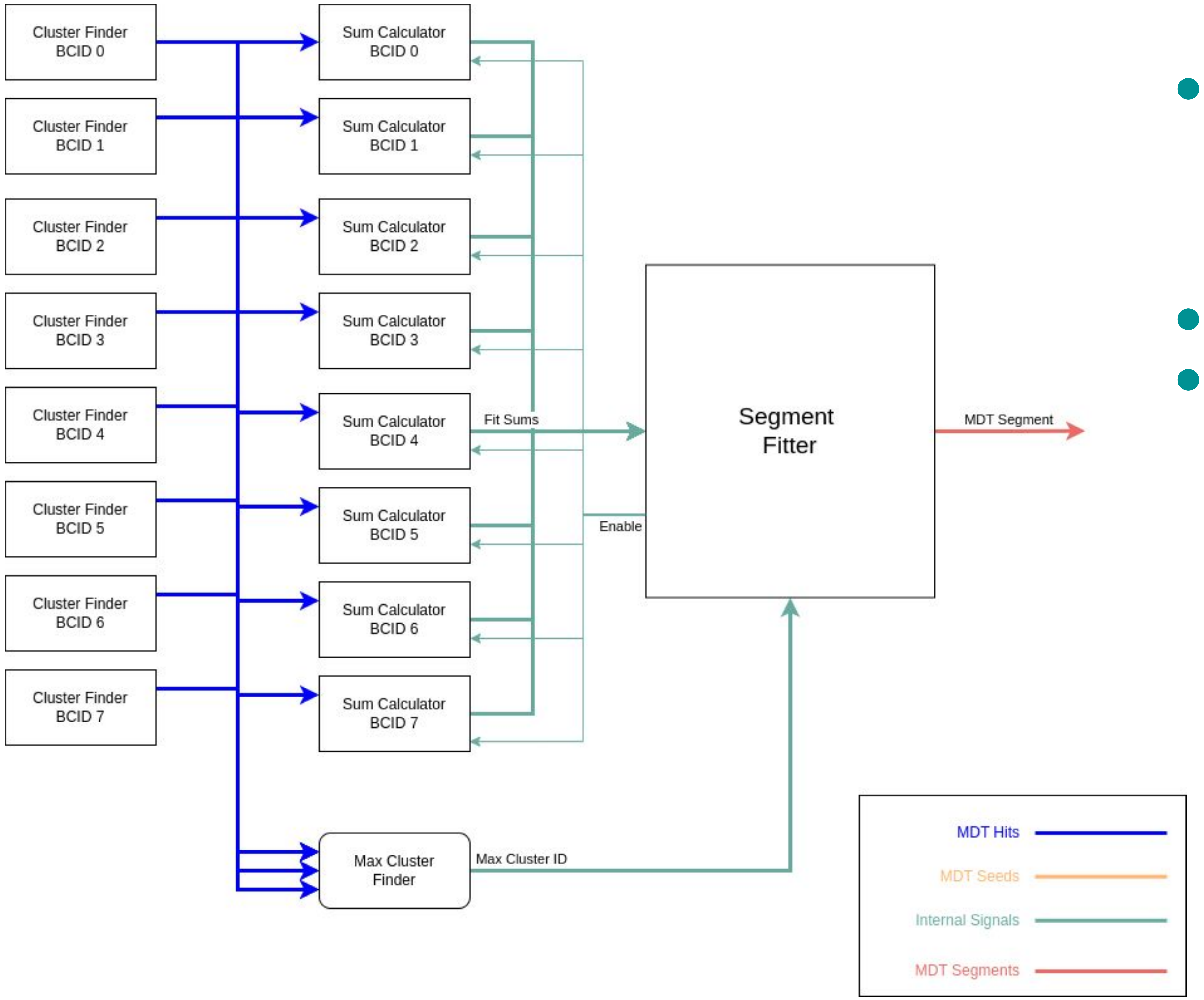
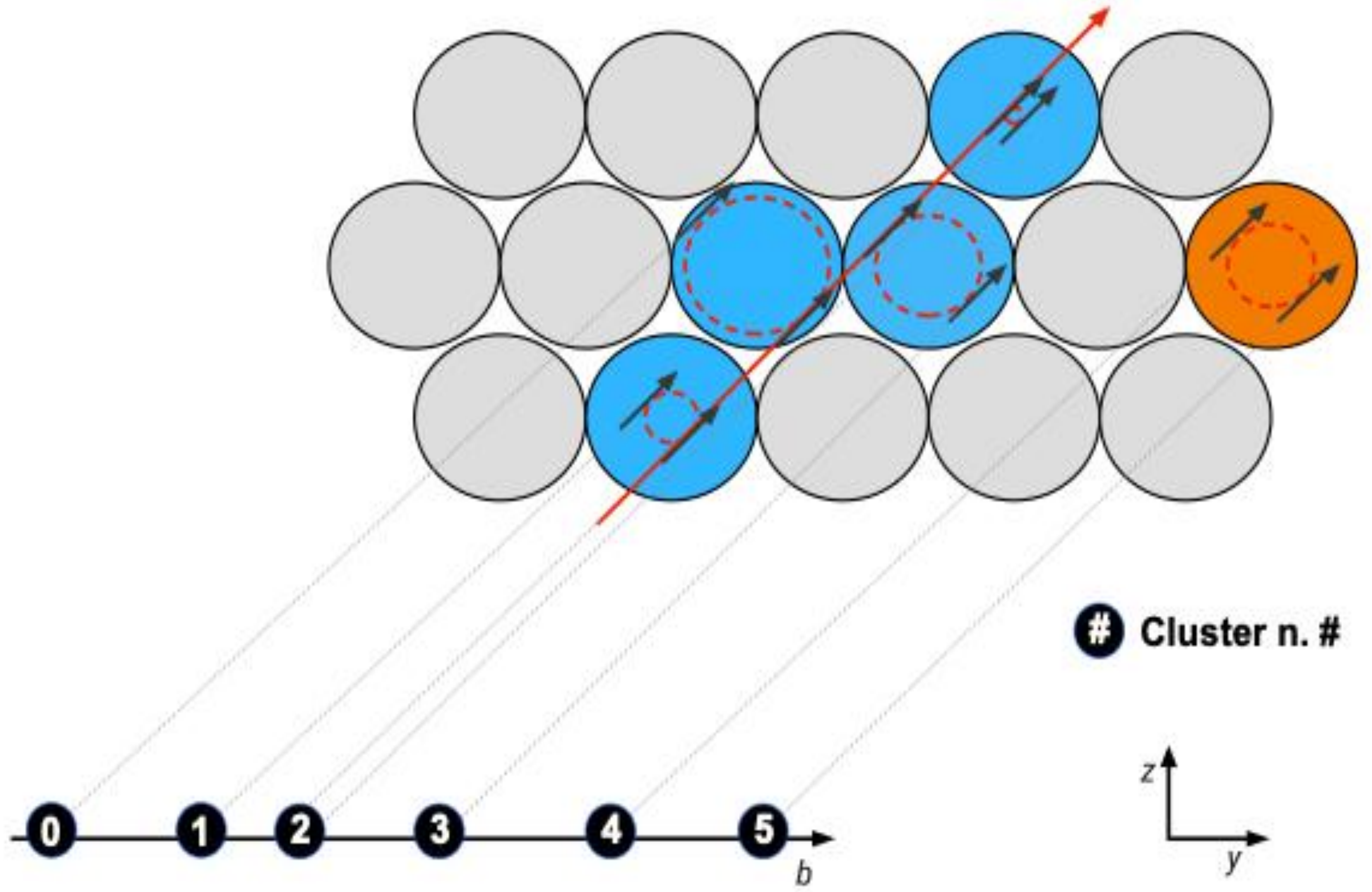
Thanks for listening!
Any questions?

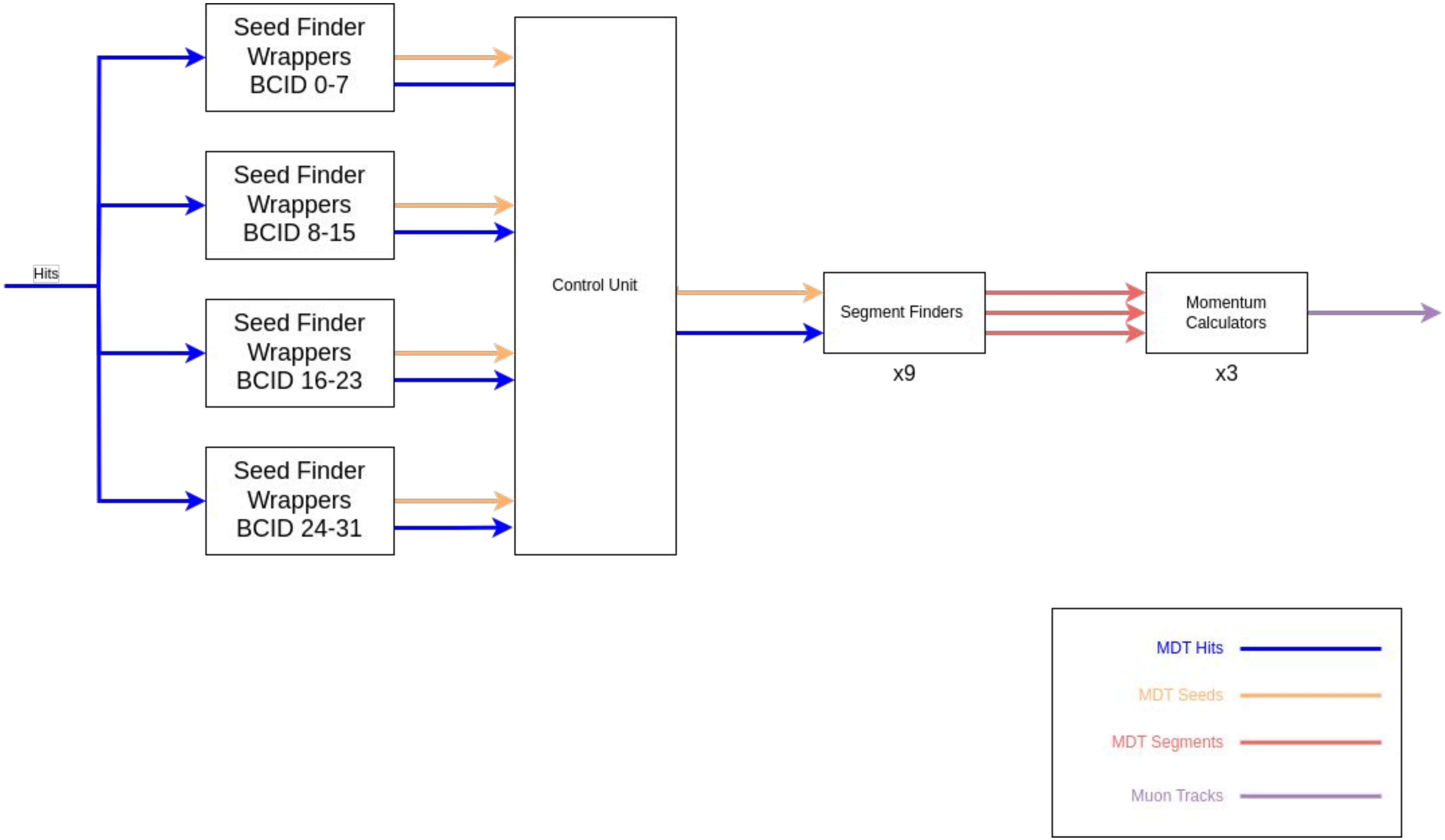
Segment Finder



- Segment Finder developed above the current Compact Segment Finder implementation
- In addition to Segment parameters, Segment Finder shall also find the correct BCID
- 8 *Cluster Finder* blocks receives the hits on the road and the *seed* parameter
  - Hit drift time is calculated and clusters are created along the intercept axis
- Best cluster identified with highest hit content
- Hit positions calculated and used to fit track segment

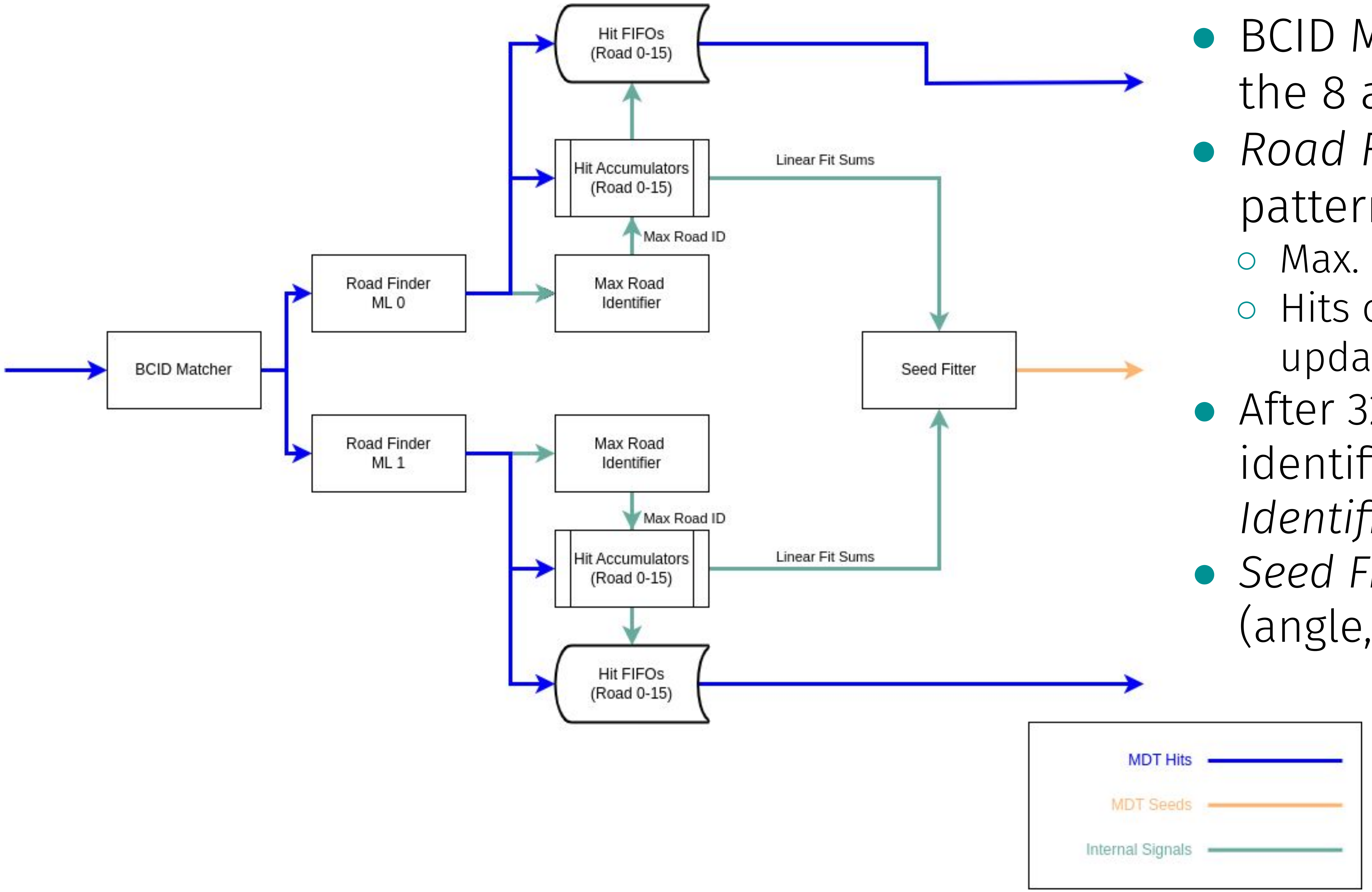


Firmware Implementation



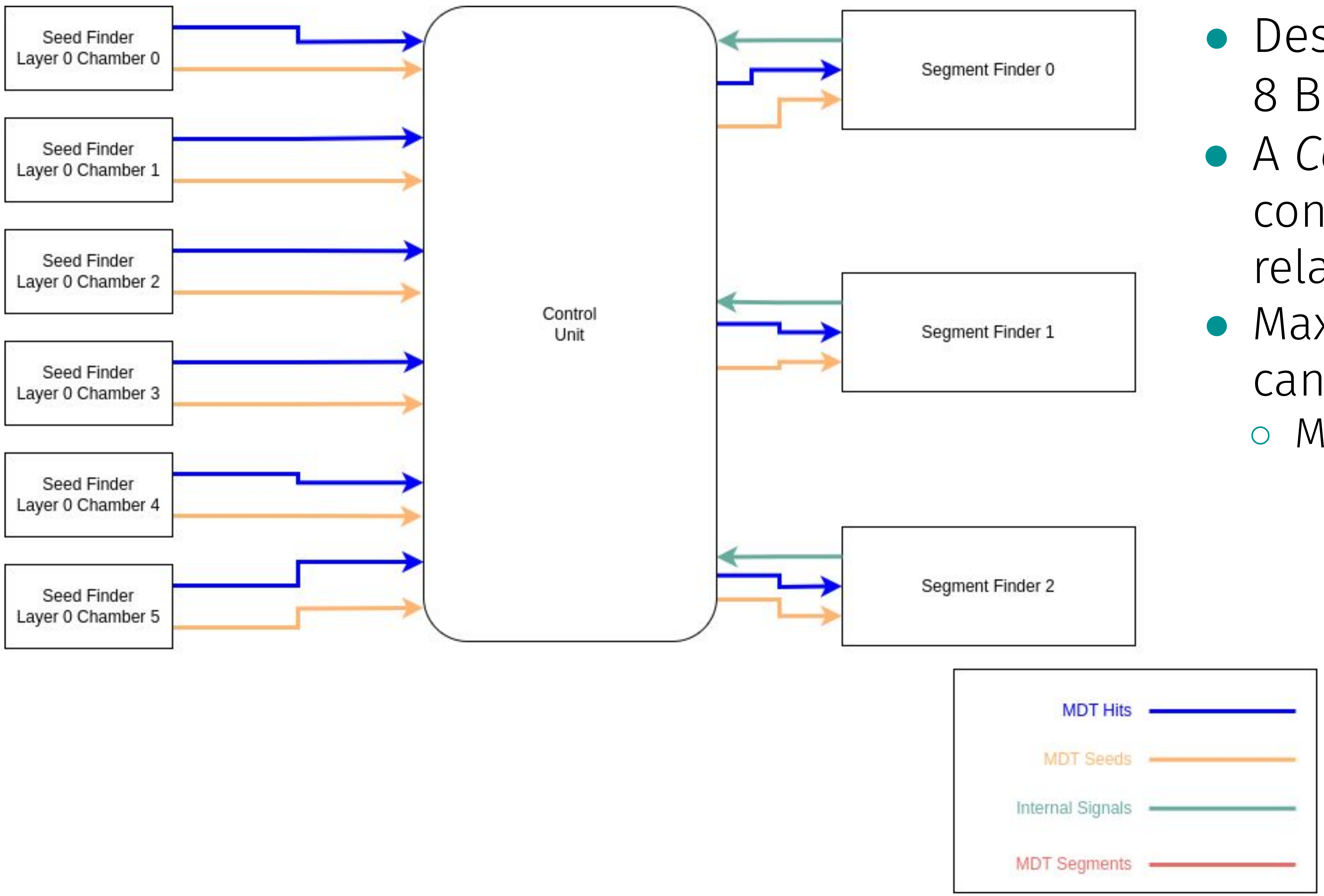
- Each Seed Finder Wrapper checks compatibility with 8 BCIDs
  - After 32 BCs, wrapper BCIDs is automatically increased by 32
- Number of Segment finders is extracted by the maximum number of reconstructed tracks per BCID (3) multiplied by the number of MDT layers (3)
- Number of Momentum calculator is equal to maximum number of reconstructed tracks per BCID

Seed Finders



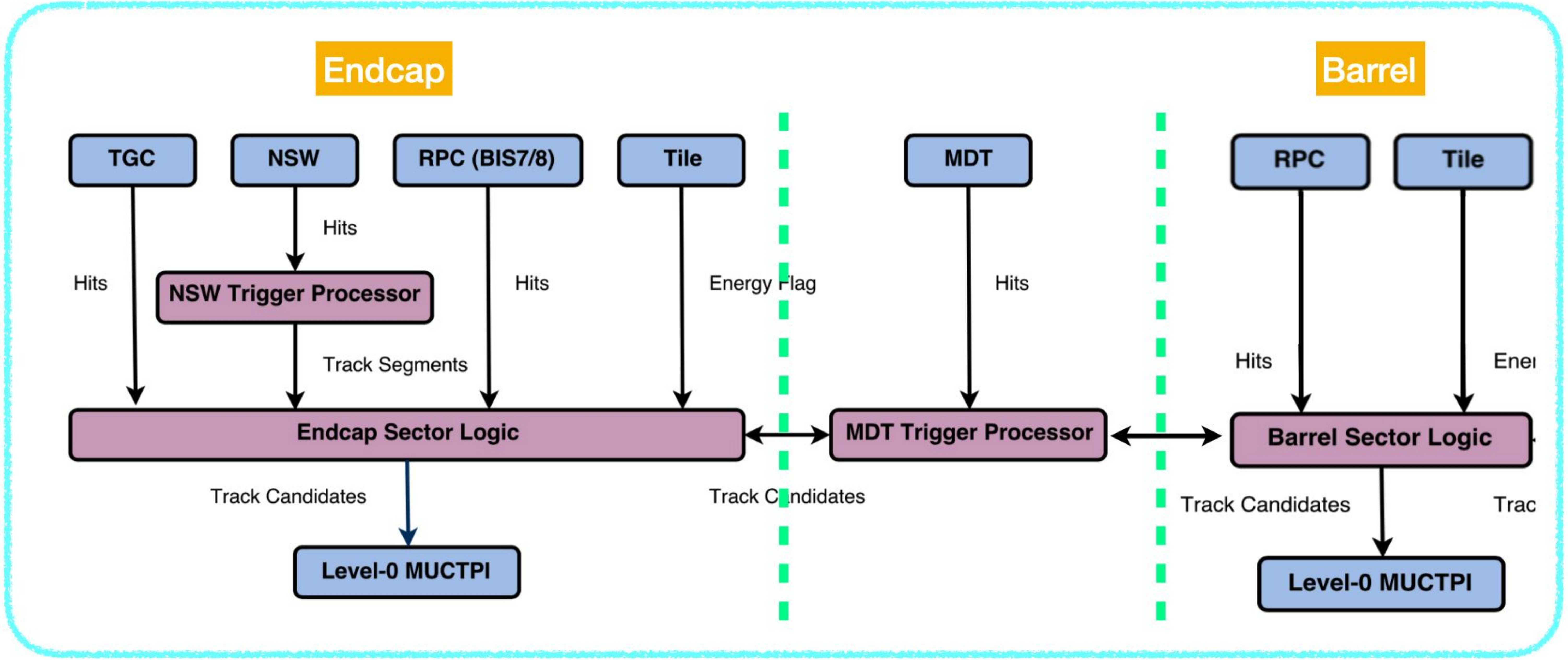
- For each MDT chamber, a Seed Finder block is instantiated
- BCID Matcher checks compatibility with the 8 assigned BCIDs
- *Road Finders* checks for predefined hit patterns in the two MDT multi-layers
  - Max. number of roads is 16 per ML
  - Hits on road are stored in FIFOs, and used to updated fit sums to improve latency
- After 32 BCs, the road with max. no. hits is identified and readout (*Max Road Identifier*)
- *Seed Fitter* calculates seed parameters (angle, position) using max road sums

Control Unit



- Design allows a maximum of 3 tracks every 8 BCs per sector
- A *Control Unit* block is instantiated to connect the calculated MDT seeds and relative hits to a free *Segment Finder*
- Maximum number of tracks is arbitrary and can be increased accordingly
  - More FPGA resources

Baseline L0Muon Architecture



- Sector Logic (SL) boards reconstruct muon tracks with data from RPC/TGC/NSW/Tile detectors
- **MDT data** available at **L0 for first time** to improve quality of SL trigger candidates
- 64 MDT Trigger Processors (**MDTTP**) reconstruct muon tracks using MDT and Sector Logic (SL) data