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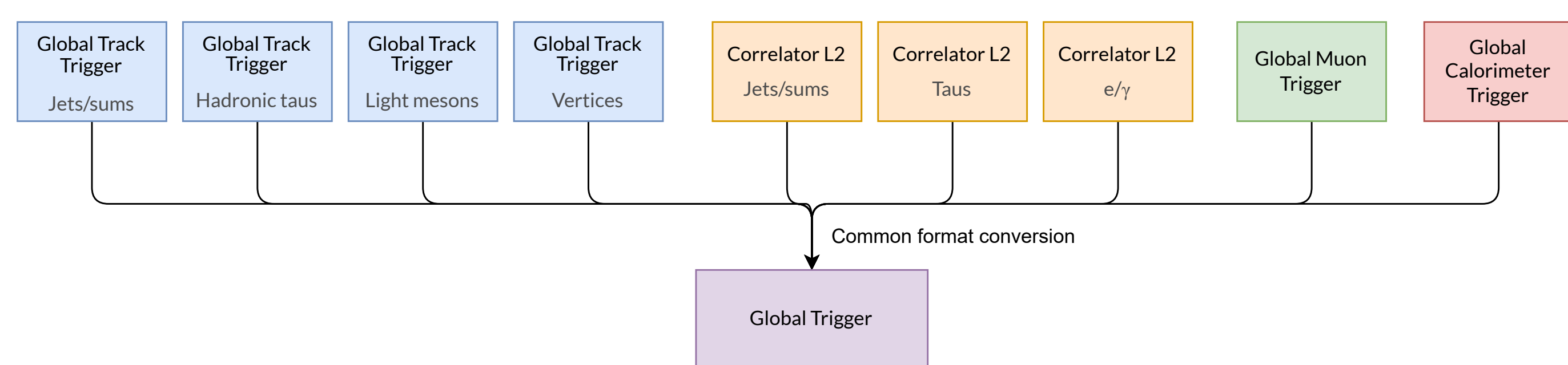
Adaptability and efficiency of the CMS Level-1 Global Trigger firmware implementation for Phase-2

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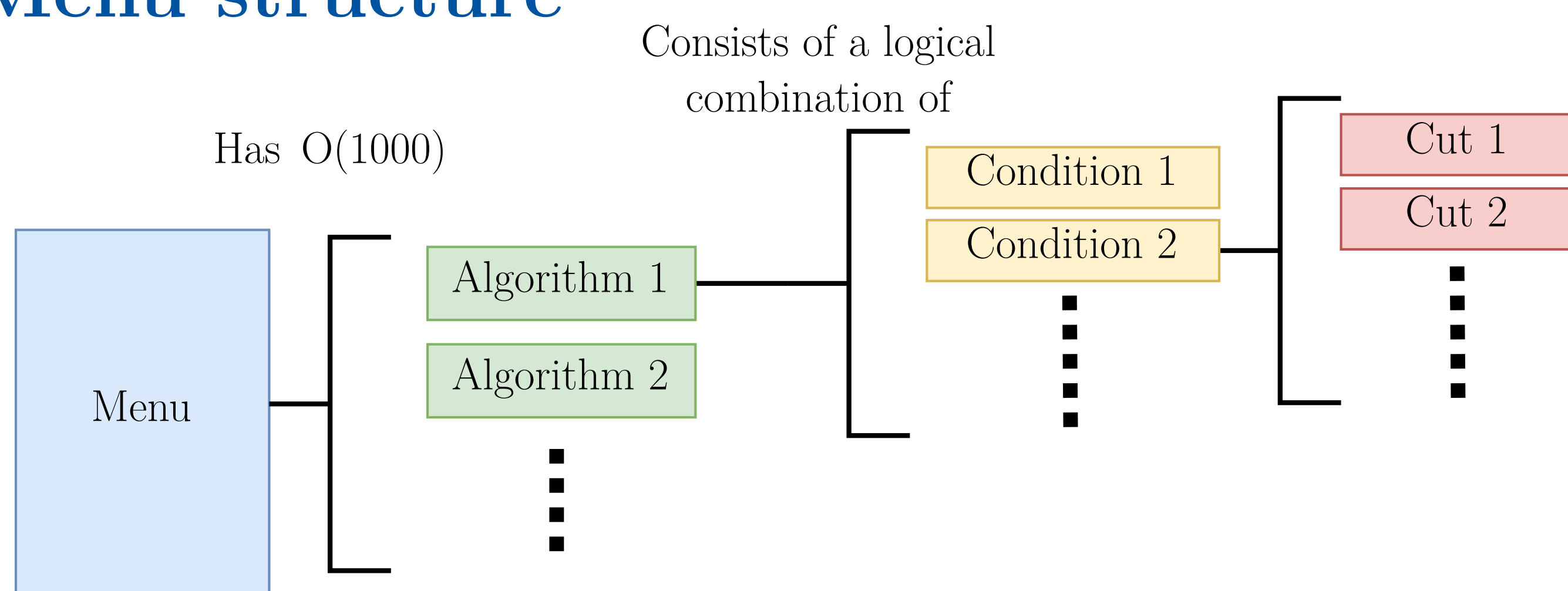
Introduction

To ensure the physics performance is maintained or even improved under the new high-luminosity conditions during Phase-2 operation, the CMS Level-1 Global Trigger is being entirely redesigned. The new system is expected to evaluate a menu of $O(1000)$ cut-based and neural-net-based algorithms by processing more than 26 trigger object collections from four different upstream trigger systems.



Upstream trigger systems interfacing with the Level-1 Global Trigger.

Menu structure



Schematic drawing of the menu building blocks. Conditions are combined with logical operations ("and", "or", "not") to form algorithms.

The basic building blocks of cut-based algorithms are conditions. Conditions facilitate a defined number of cuts on up to four Global Trigger object collections. The four different conditions (Single, double, triple, quad) differ by the number of objects of interest in an event.

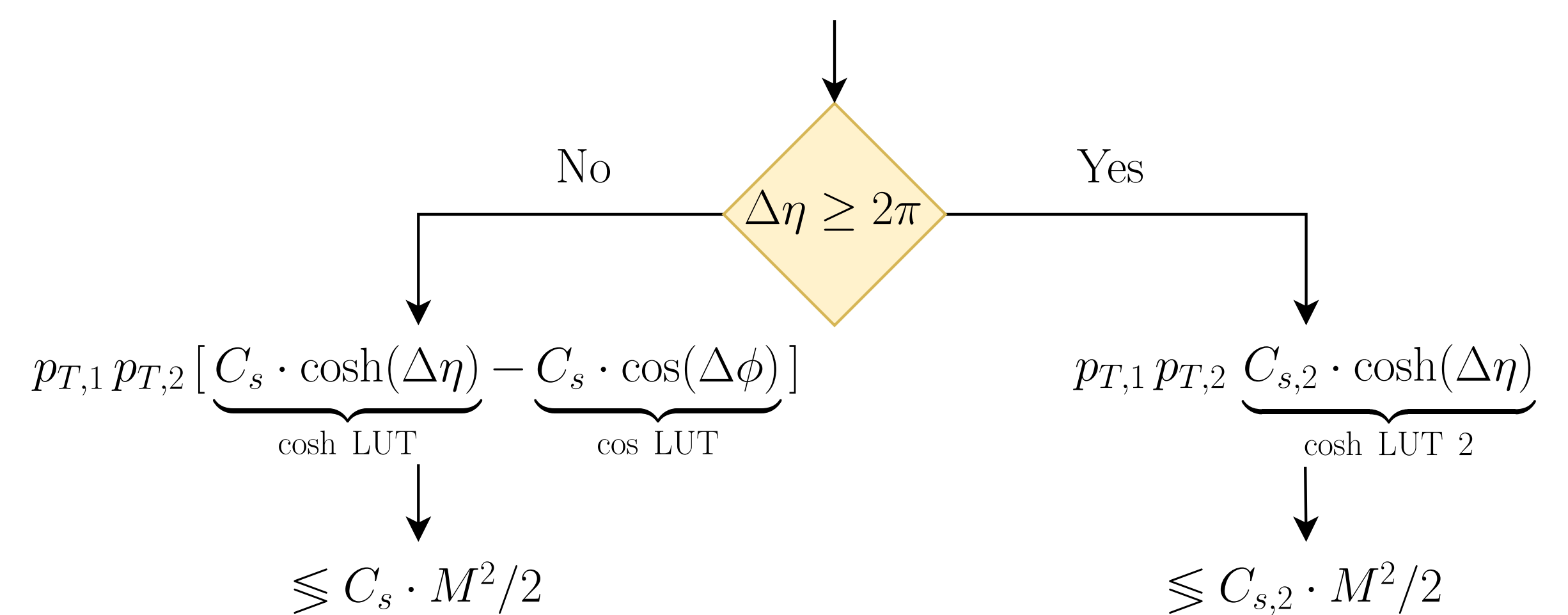
Quantity to cut on	Single	Double	Triple	Quad
p_T	✓	✓	✓	✓
η	✓	✓	✓	✓
ϕ	✓	✓	✓	✓
z_0	✓	✓	✓	✓
isolation/ p_T	✓	✓	✓	✓
$ z_0 - z_{0,VTX} $	✓	✓	✓	✓
Correlational cuts on double-object subsets				
$q_1 = q_2$		✓	✓	✓
$q_1 \neq q_2$		✓	✓	✓
$\Delta\eta$		✓	✓	✓
$\Delta\phi$		✓	✓	✓
$ \Delta z_0 $		✓	✓	✓
$\Delta R (= \sqrt{\Delta\eta^2 + \Delta\phi^2})$		✓	✓	✓
M (invariant mass)		✓	✓	✓
M_T (transverse mass)		✓	✓	✓
P_T (two particle transverse momentum)		✓	✓	✓
$M/\Delta R$ (invariant mass over ΔR)		✓	✓	✓
3-body checks on triple-object subsets				
$M (= \sqrt{M_{1,2}^2 + M_{1,3}^2 + M_{2,3}^2})$			✓	
$M_T (= \sqrt{M_{T,1,2}^2 + M_{T,1,3}^2 + M_{T,2,3}^2})$			✓	

Currently implemented cuts by condition type.

Contact Information

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Invariant mass calculation



Invariant mass calculation split at 2π ($\cosh(2\pi) \simeq 268$), for good relative accuracy in both $\Delta\eta$ regimes.

Adaptability

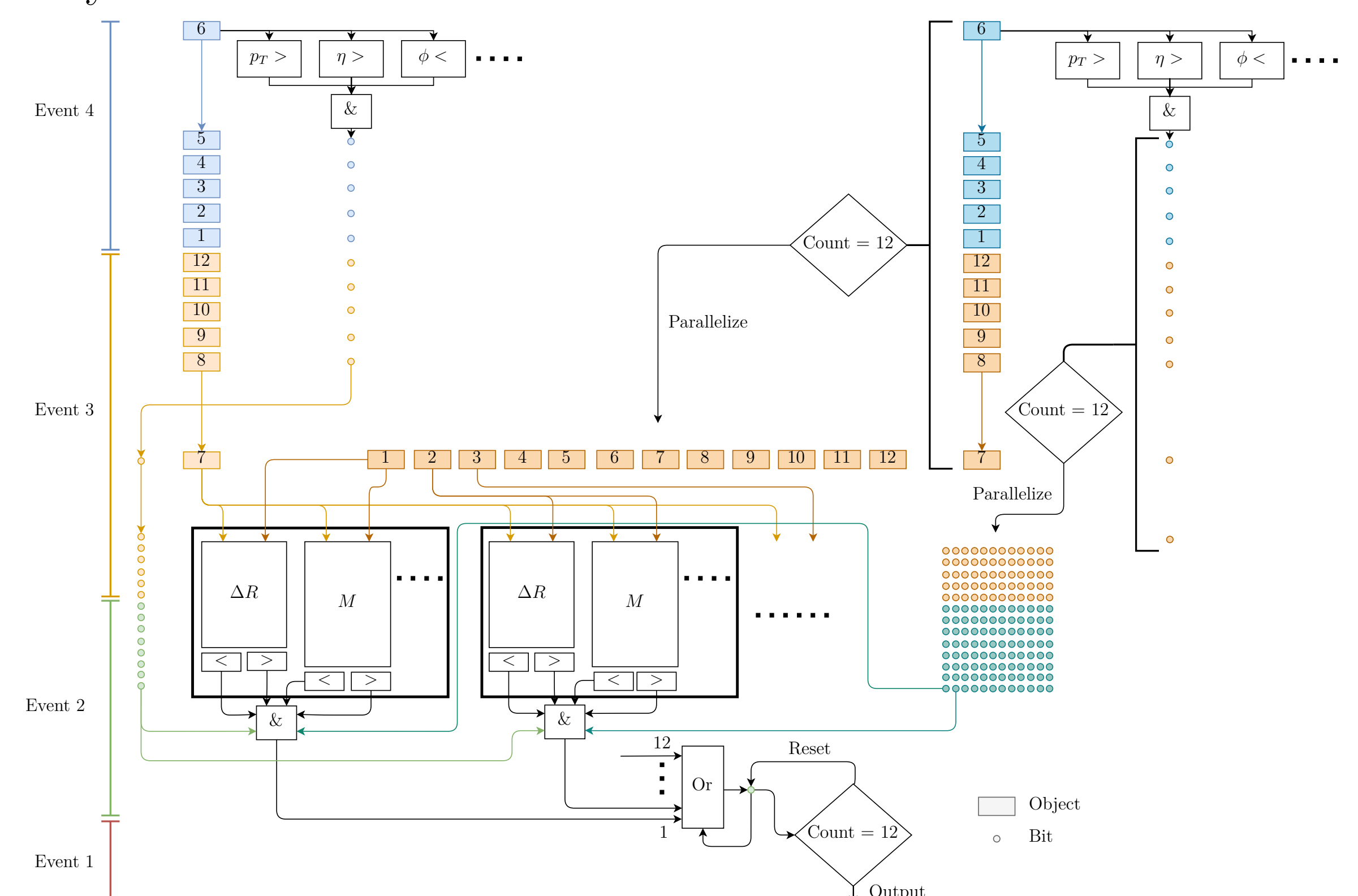
```
triplePuppiJet_70_50_35 : entity work.p2gt_tripleObjCond
generic map(
  collections          => (CL2Jets, CL2Jets, CL2Jets),
  minPT_cuts          => (70, 50, 35),
  minPT_cuts_enabled  => (true, true, true),
  minDEta_cuts        => (40, 40, 40),
  minDEta_cuts_enabled => (true, true, true),
  maxDEta_cuts        => (200, 200, 200),
  maxDEta_cuts_enabled => (true, true, true),
  min3BodyInvMassSqrDiv2_cut => 1200.0,
  min3BodyInvMassSqrDiv2_cut_enabled => true,
  max3BodyInvMassSqrDiv2_cut   => 4000.0,
  max3BodyInvMassSqrDiv2_cut_enabled => true
)

```

A triple-object condition module instantiation exhibiting the high adaptability of our condition modules.

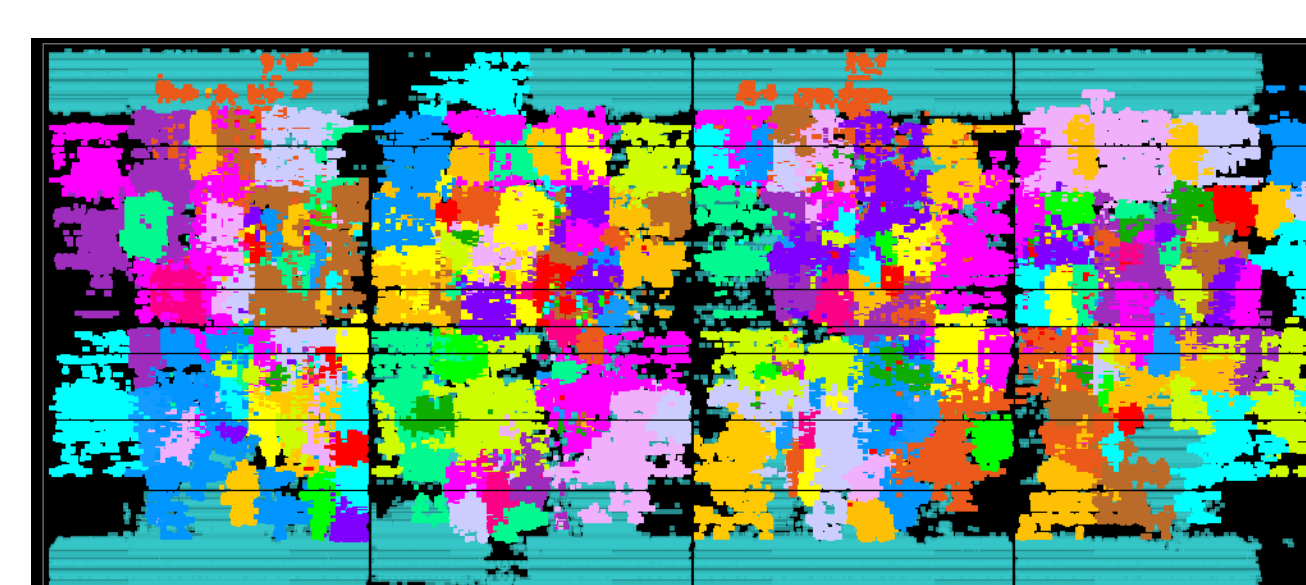
Hardware implementation

Compared to the current Run 3 implementation, which runs at 40 MHz, the Phase-2 implementation operates at 480 MHz, and we can thus serialize the checks and calculations. This reduces the resource usage for individual checks by a factor of 12.



Flow-plan of the double-object condition with single and correlational cuts.

Events (bunch-crossings), each consisting of up to twelve objects, flow from top to bottom. The whole double-object pipeline is always filled with four subsequent events, coloured in red, green, orange and blue. Operations, like comparison and calculations, are denoted by labelled blocks.



LUTs: 33.9% abs.
Flip-Flops: 36.6% abs.
BRAM: 87.4% abs.
DSPs: 52.8% abs.

Floor-plan of the Global Trigger firmware implemented on a Xilinx Virtex Ultrascale+ (VU13P) FPGA. Each color represents one of 368 implemented algorithms.