The Particle Flow Algorithm in the Phase II Upgrade of the CMS Level-1 Trigger

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Particle Flow & PUPPI in Level-1 Trigger

Inclusion of tracking at L1, combined with Calo and Muon

Efficient tracking, fine granularity calorimetry allows online PF PUPPI

Part of Correlator Trigger

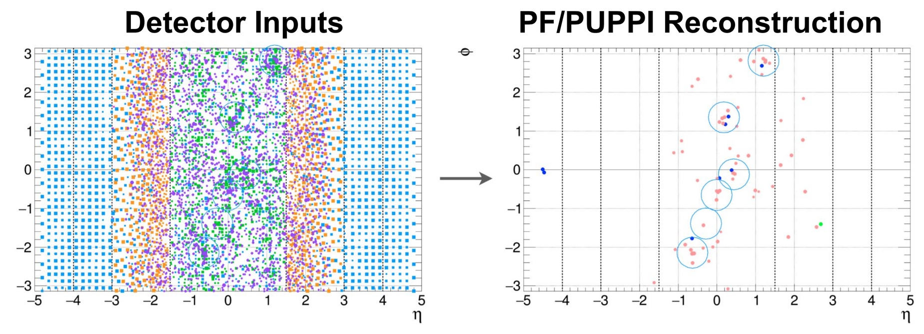
1. Layer 1 PF PUPPI, Combine all detector information
2. Layer 2 PF PUPPI Objects then used as input for jets, tau, sums, isolation

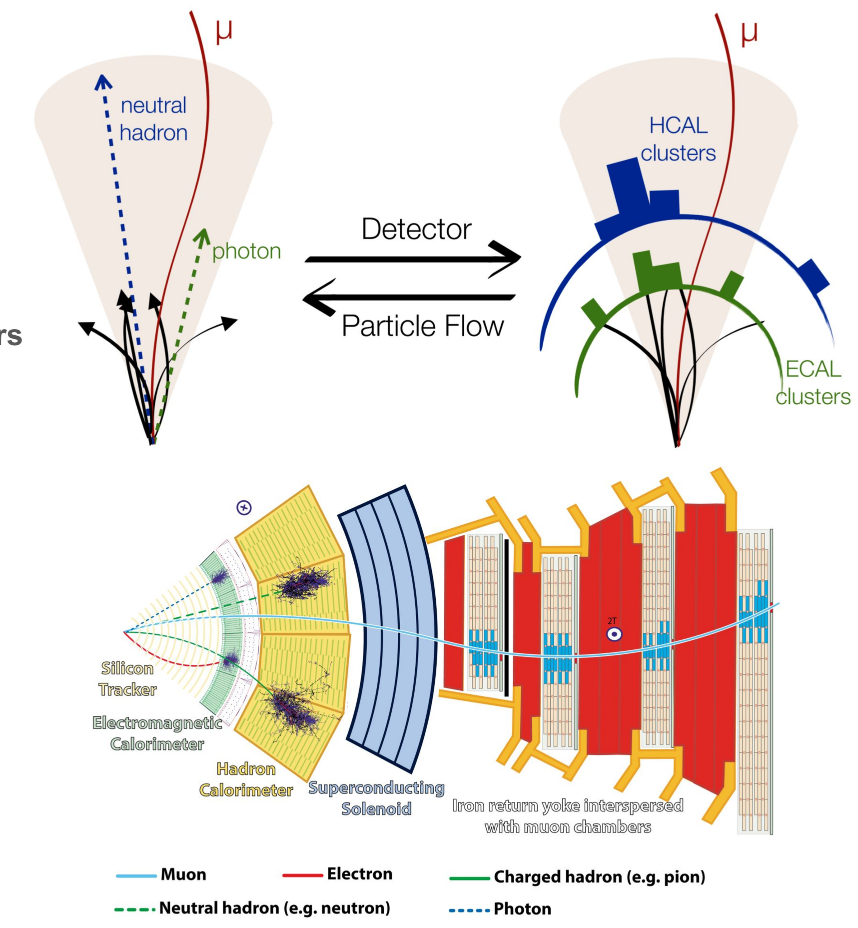
The goal of the Correlator Trigger is to calibrate and combine information from different sub-detectors to build PF/PUPPI objects in layer 1, and then to build objects such as jets with those PF/PUPPI object in layer 2, to build trigger logic with those high level objects.

High pile-up in HL-LHC environment PF PUPPI are necessary, and PF PUPPI objects used for downstream algorithms with higher level objects

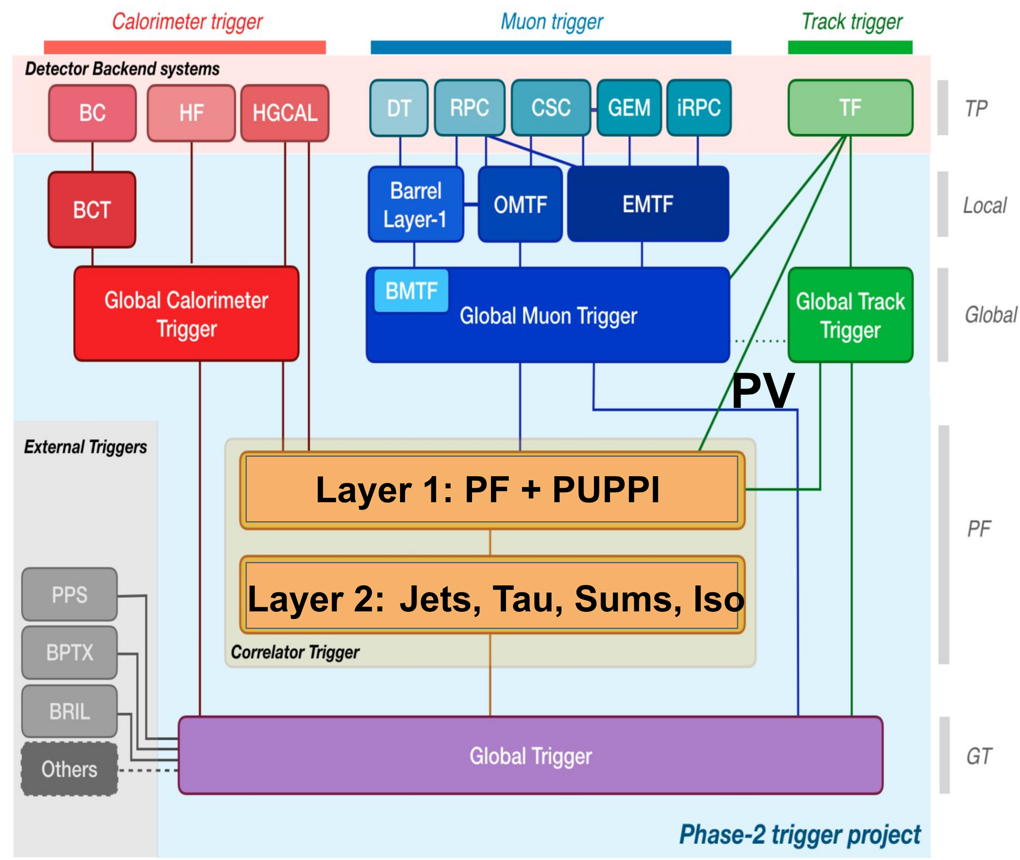
Detector subdivided into eta-phi **regions**, process the regions separately

Detector Inputs **PF/PUPPI Reconstruction**





Level 1 Trigger Diagram



Layer 1 Firmware Implementation

In Layer 1, sub-detector inputs are regionized, then we link objects to build PF, then PF with PV we get weighted PUPPI

Full detector at 40MHz, Fixed Latency <1μs, Firmware implemented and tested in Xilinx VU9P FPGA on prototype boards, might change to newer chips in the future

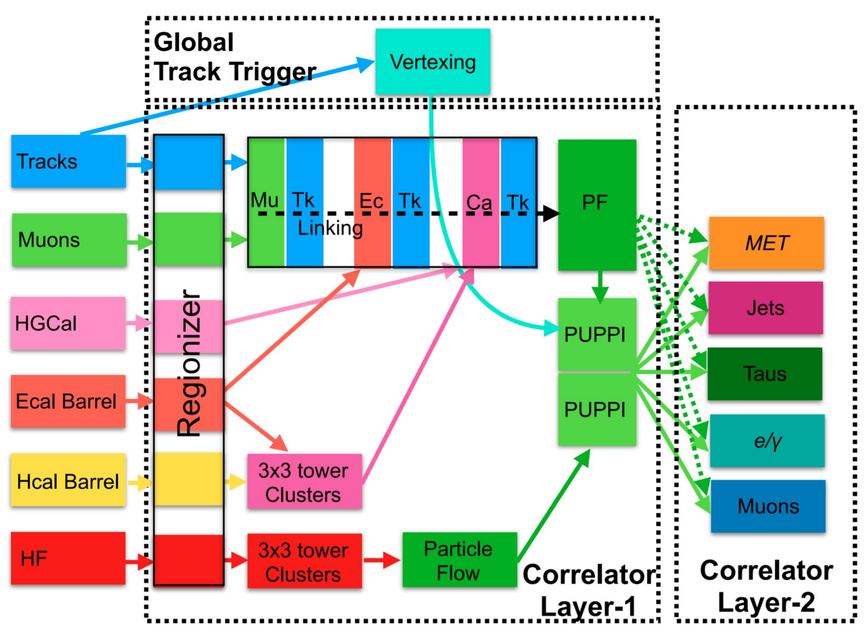
Fast FPGA firmware development of complex algorithms with High Level Synthesis (HLS) tools, and stitch together with optimized VHDL algorithms(regionizing, sorting, shifting, infrastructure)

Different Initiation Interval (II) and region numbers vs FPGA resources studied (possible with HLS tools)

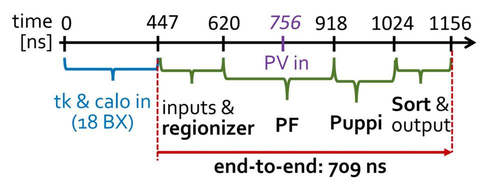
36 boards(18 barrel, 18 endcap) at TMUX=6, 6 boards/BX, 9 Clocks/BX, 18 regions/board(Barrel), 9 regions/board (endcap)

- Endcap: in each region max 30 tracks, 20 clusters, 4 muons → 18 highest pT sorted puppi candidates
- Barrel: in each region max 25 tracks, 18 calo, 12 emcalo, 2 muons → 18 highest pT sorted puppi candidates

Algorithm meets timing, and perfect agreement is achieved between the regionizer firmware and software emulation → Now let's build higher level objects!

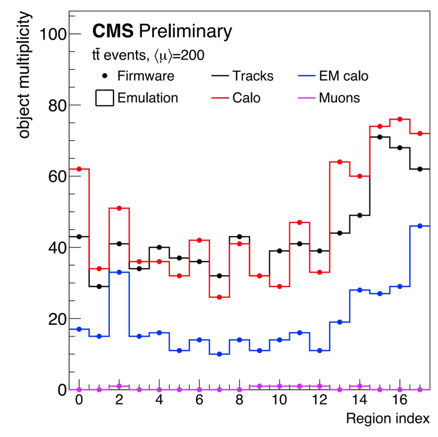


Latency Budget

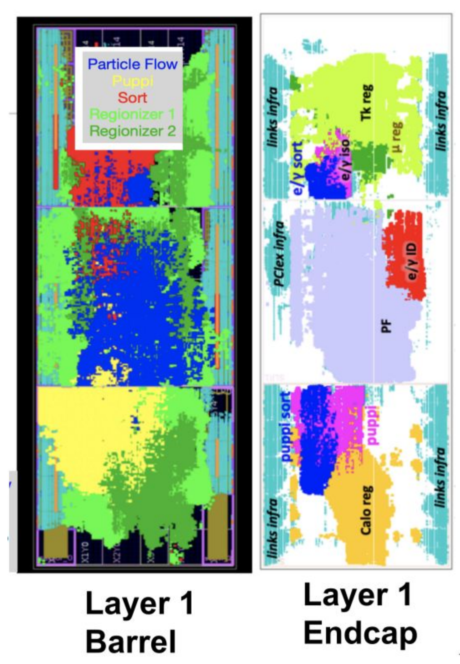


II = 4 for the endcap (16ns)
II = 2 for the barrel (8ns)

Firmware vs Emulation



FPGA (VU9P) Floorplan



Layer 2 Algorithms & Firmware

30 boards, receive input from layer 1 at TMUX=6 via 25Gbps links, each layer 1 board sends up to 162 PF/PUPPI candidates (64 bits) on 3 link to each layer 2 board

With PF PUPPI object inputs from Layer 1, we can build higher level objects:

Jets, Taus, Sums, Isolation, for each object consider a range of algos

CT output sent to GT on 30, 25-Gbps links, meaning we can output 27 objects (128 bits per object).

Seeded Cone Jet Algorithm

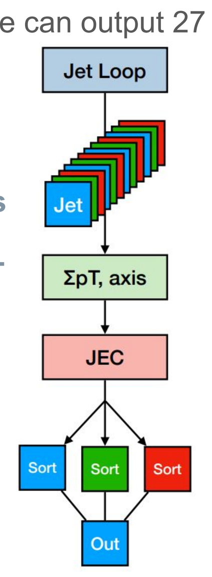
Jets constructed in layer 2 using PF/PUPPI particles

Construct cone of fixed ΔR around seed (leading pT particle), adding parts within cone to jet

Compute jet pT, η, and ϕ from parts

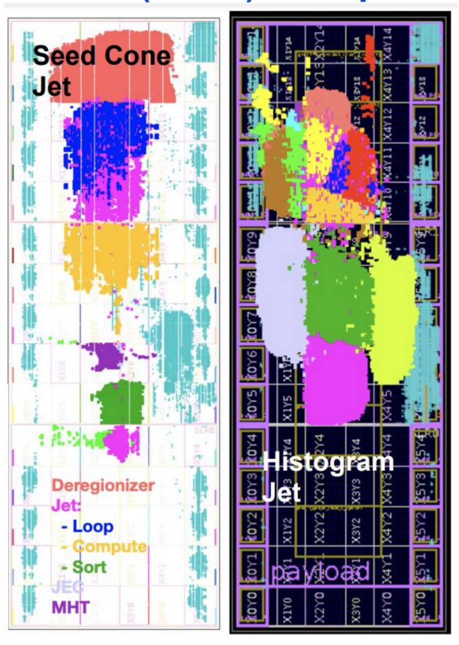
Add in jet energy corrections (JEC)

Aggregate data and sort jets, compute HT and MHT



Primary colours represent different events

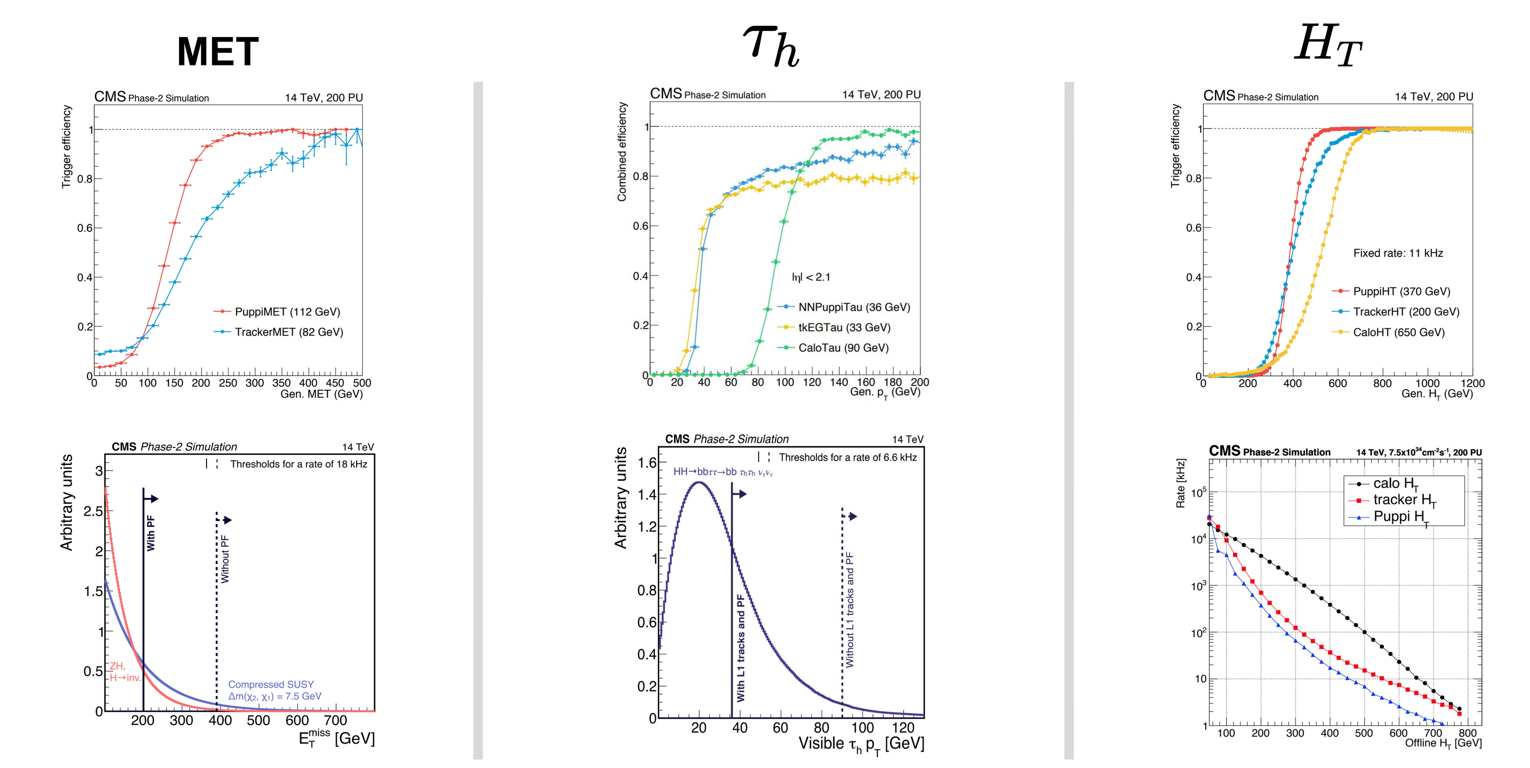
FPGA (VU9P) Floorplan



Trigger Performance & Physics Implications

Performance improvement vs Calo or Track only

PF + PUPPI allows for sharper & earlier turn ons, major gains in signal acceptance



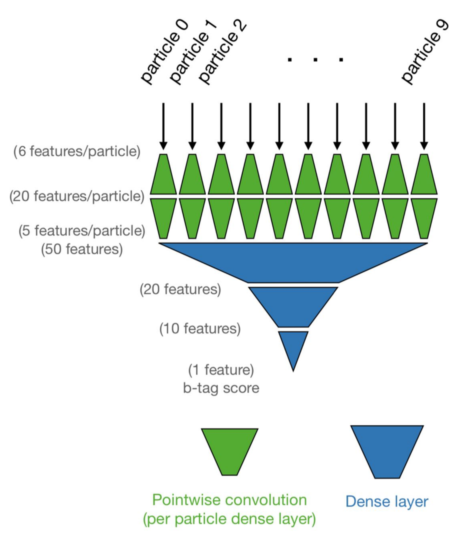
Level 1 b Tagging

b Tagging at Level 1 made possible by PF + PUPPI

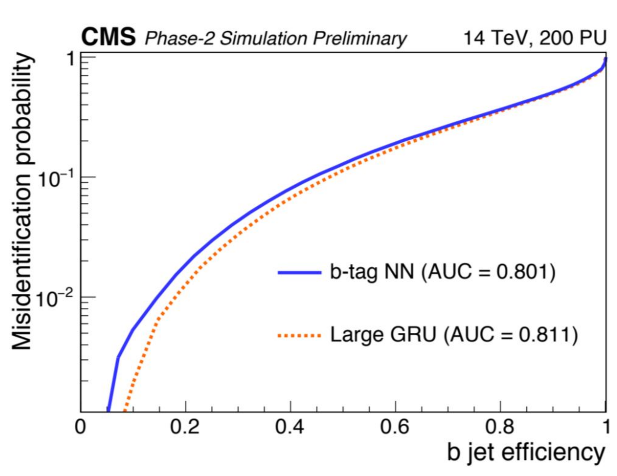
b tag neural nework applied to *HH→bbbb* channel allows for greatly reduced energy thresholds leading to large increases in signal efficiency especially for low energy events which are more valuable for analysis of Higgs self coupling

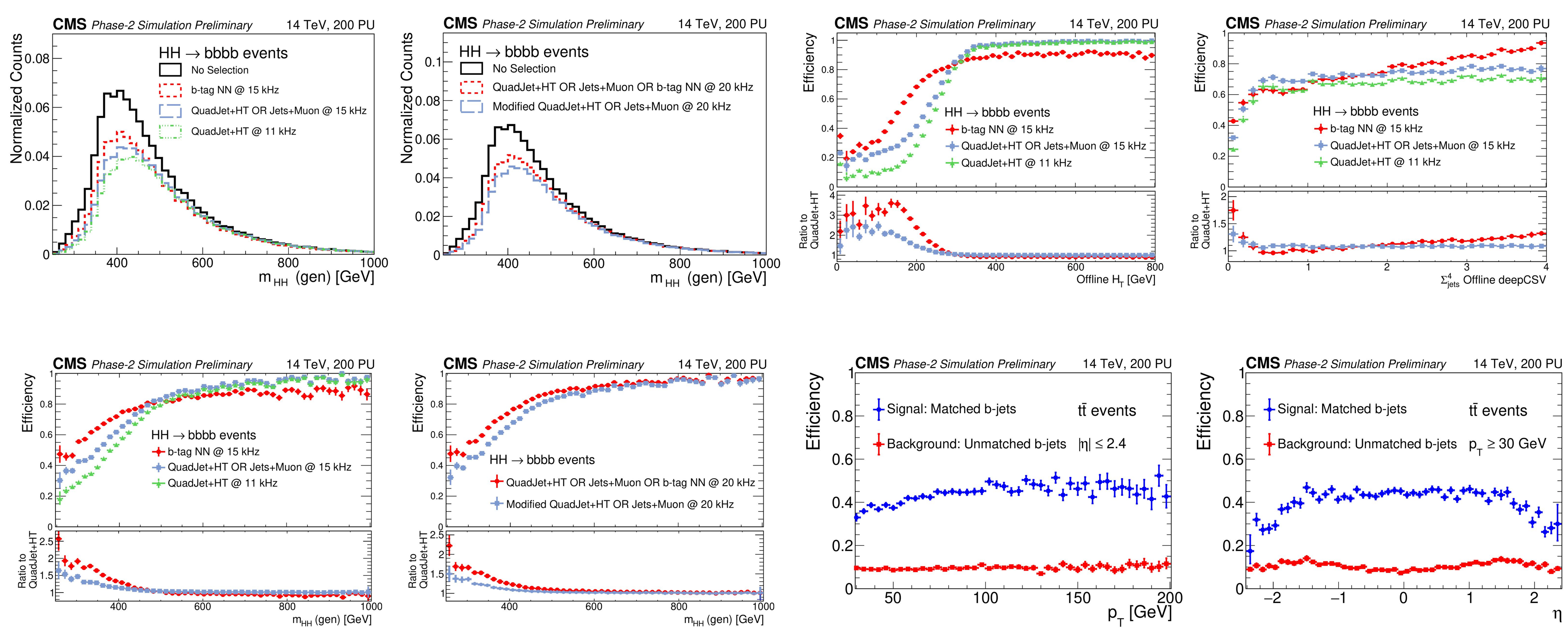
Firmware development underway to integrate this network into Layer 2

b Tag NN Schematic



b Tag NN ROC Curve





References

The Phase-2 Upgrade of the CMS Level-1 Trigger. Technical Report CERN-LHCC-2020-004. CMS-TDR-021, CERN, Geneva, Apr 2020. URL http://cds.cern.ch/record/2714892

B. Kreis, "Particle Flow and PUPPI in the Level-1 Trigger at CMS for the HL-LHC," [arXiv:1808.02094[physics.ins-det]].