VBF Higgs to Invisible Run 2 trigger

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Today's presentation

Topics

- CMS Detector
- Legacy system
- Upgrade system
- VBF Higgs to invisible signature
- Designing a new trigger

Me @ CMS

Masters

- $t\bar{t} \rightarrow b\bar{b}e\tau$ and $b\bar{b}\mu\tau$
- minimal Universal Extra Dimension $\rightarrow$ 3-4 leptons
- ECAL service work

CERN Engineer Internship

- Level 1 Trigger Monitoring

PhD (3rd-ish year... not really)

- *Higgs* $\rightarrow \gamma\gamma$ Spin analysis
- VBF *Higgs* $\rightarrow$ *Invisible*
  - Trigger designed (2012 and 2015)
  - Analysis development
  - Cross check analysis

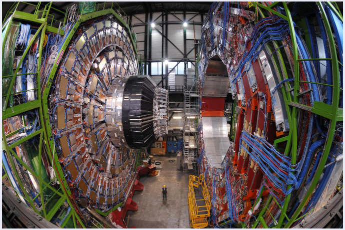
The LHC-CMS Experiment

Large Hadron Collider

- Located at Franco-Swiss border near Geneva, Switzerland.
- Synchrotron Machine (currently the most powerful in activity)
- Designed to collide protons up to $\sqrt{s} = 14\ TeV$
  - 2011: $\sqrt{s} = 7\ TeV$
  - 2012/13: $\sqrt{s} = 8\ TeV$
  - 2015: $\sqrt{s} = 13\ TeV$

Compact Muon Solenoid

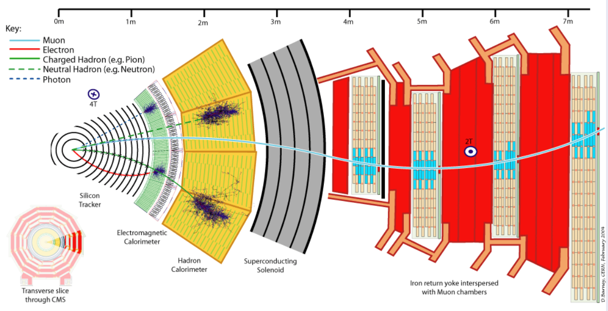
- Located at LHC Point 5
- General purpose experiment
- Objective of studying a broad spectrum of physics
- Classical onion structure
- Solenoid with highest stored energy ever built (2.66 GJ at 4.0 T)



Particle Detection on CMS

When a collision happens then resulting particles need to be identified and measured

Detector Structure



- Tracker
  - Charged particle trajectory
- ECAL and HCAL
  - Energy Measurement
- Solenoid
  - Charge and Momentum
- Muon Chambers
  - Muon identification and measurement
- Trigger (L1+HLT)
  - Event Selection

- Detector subsystems are designed to take advantage of particle characteristics in order to identify and measure their characteristics.
- Trigger System is responsible to select only the most interesting events

CMS Trigger System Overview

CMS has a 2 level trigger system

Collisions

At maximum operating capability during run 2 the LHC will

- Collide bunches every 25 ns
- Over 50 simultaneous collisions per bunch crossing

Level 1 Trigger

- Hardware based system
- System will have to take decisions at 40 MHz
- Can only allow ~ 100 kHz events to pass
- Limited amount of event information and time for calculation

High Level Trigger

- Software based system (running on a CPU farm)
- Can only allow ~ 1 kHz events to be recorded
- Almost full information about the event

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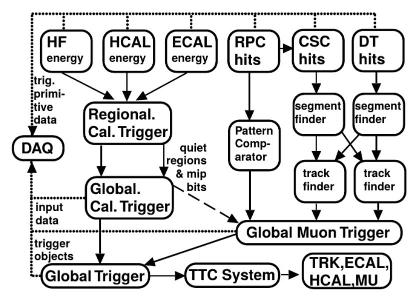
CMS Legacy L1T Trigger

Description

- Calorimeter data e gathered into regions
- Muon segment are found (taking system overlap into account)
- Global calorimiter objects and sums are computed
- Global muon information is merged
- Global trigger evaluates algorithms
- Final decision is sent back to detector and DAQ

Diagram



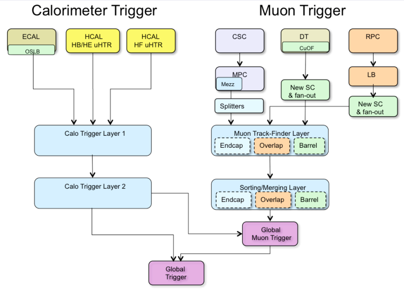
CMS Upgrade System Trigger

Besides more $\sqrt{s}$ energy in run 2 we will almost double the number of interaction per bunch crossing and double the crossing rate. Legacy still will struggle to deal with this. We need a new Level 1 trigger!

Description

- No regional calorimeter data gathering
- No system specific track searching
- Global calorimeter object and sum calculation
- Global (by region) muon track finding
- Calorimeter information is shared with muon (for isolation calculation)
- Global trigger evaluates algorithms
- Final decision is sent back to detector and DAQ

Diagram



Also we are implementing a new global architecture for the whole L1T. Instead of processing events linearly event by event they will be time multiplexed over several cards each with full access to all event information.

New L1T possibilities

Hardware:

- More flexibility
  - Large FPGA and memory resources
  - Higher bandwidth via optical links
- Less card diversity (small number of general-purpose cards)
- Upgrade system will run in parallel with legacy system (at least initially)

Algorithms:

- PU subtraction
- Better jet position and energy resolution
- Incorporation of forward jets from HF (important)
- Possible inclusion of HF in energy sums (important for MET)
- Much better τ identification
- Isolated Muon Isolation algorithms (Additional system interconnection)
- Possibility of more complex calculations at L1T:
  - Invariant Mass triggers
  - Better b-tagging of jets (jets with a muon)
  - Angular separation ($\Delta\eta$, $\Delta\phi$, etc)
  - Other advanced algorithms (your idea can be here!)

Lowest seeds

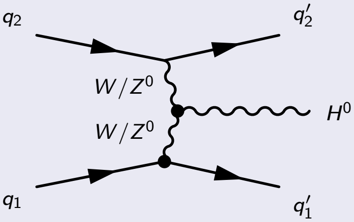
The beam conditions are $\sqrt{s} = 14$ TeV and $L = 2.2 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ with a bunch spacing of 25 ns and pile-up of 50

Seeds

	Current Level-1 $L = 2.2 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$			Upgraded Level-1 $L = 2.2 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$		
Trigger Algorithm	Rate [kHz]	95% Threshold [GeV]	Plateau Efficiency	Rate [kHz]	95% Threshold [GeV]	Plateau Efficiency
Single e/γ	10	67	1.0	11	57	1.0
Single iso e/γ	9.4	52	0.9	15	31	0.90
Single Mu	11	42	0.95	14	22	0.90
Single iso Mu	NA	NA	NA	15	19	0.82
Single Tau	NA	NA	NA	12	100	0.95
Single iso Tau	9.2	72	0.3	13	83	0.7
iso e/γ + e/γ	16	26 16	0.9	12	23 16	0.9
(iso)Mu + Mu	7.4	20 12	0.9	9.4	15 10	0.8
(iso)Tau + Tau	8.2	36 36	0.1	7.2	64 62	0.67
iso e/γ + Mu	6.2	24 12	0.85	11	21 10	0.85
(iso)Mu + e/γ	5.0	20 15	0.95	8.3	18 15	0.83
iso e/γ + Tau	NA	NA	NA	8.3	21 57	0.86
isoMu + Tau	NA	NA	NA	5.8	14 47	0.8
Single Jet	5.4	205	1.0	5.9	205	1.0
Double Jet	5.8	170 170	1.0	4.2	130 130	1.0
Quad Jet	4.8	4@96	1.0	5.0	4@55	1.0
Single iso e/γ + Jet	8.5	38 82	0.9	11	27 78	0.90
Single Mu + Jet	7.5	27 54	0.95	9.7	18 52	0.93
Single iso e/γ + H_T^miss	8.2	38 120	0.9	12	27 110	0.90
Single Mu + H_T^miss	9.8	20 93	0.95	11	18 86	0.93
H_T	5.4	580	1.0	3.0	380	1.0
Total Rate	92			95		

VBF Higgs to invisible and the Trigger

Feynman Diagram



Signature

- 2 Forward jets with high dijet mass
- No color connection so no activity between jets
- Missing transverse energy

Problems

- Hadron colliders are jet factories... its easy to find 2 of them
- Some processes produce real MET (like b, W or Z decays)
- Miss measuring jets can create fake MET
- Detector effects like zero suppression can cause fake MET too
- Pile-up will provide more jets and create more complication to isolate signal

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Searching for a new trigger

Method for L1T

Monte Carlo samples where generated to simulate just overlapped minimum bias events (with no hard scattering)

- Sample replicate 3 possible scenarios of bunch separation and PU (up to 25 ns and PU 40)
- We can simulate the L1T upgrade system performance
- We can produced L1T objects to study and emulate new algorithms

Method for HLT

We cannot use the same samples as the ones used for the L1T studies (simply not enough statistics) we use QCD samples since this will be the dominant type of events passing any HLT trigger.

- Same 3 possible scenarios as before
- We can simulate the L1T+HLT upgrade system performance
- We start by requiring a specific L1T seed
- We can produced HLT objects to study and emulate new algorithms

For both L1T and HLT studies we used a grid search over several variables to meet specific rate and efficiency requirements.

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Baseline I

2012 Trigger

- L1T Seed: L1_ETM40
- HLT Path: HLT_DiPFJet40_PFMETnoMu65_MJJ800VBF_AllJets_v*
  - Dijet $p_T > 40\ GeV$, fwd/bck, $\Delta\eta > 3.5$, $m_{jj} > 800\ GeV$
  - METNoMu $> 65\ GeV$

Efficiency for $m_H = 125$, BF(Inv)=100%, $L1_{eff} =\sim 47\%$, $HLT_{eff} =\sim 9\%$

We start from the baseline L1T trigger and run grid search also run some proposals from other groups.

L1T for Run 2

Algo	Ind. Rate	Ind. Eff.	Extra Yield
ETM70 (on the menu)	$7\ kHz$	28%	-
$Dijet30 + fwd/bck + \Delta\eta(jj) > 3.5 + Jet96$	$4.6\ kHz$	15%	21%
$Dijet30 + fwd/bck + \Delta\eta(jj) > 3.5 + ETM50$	$5.0\ kHz$	14%	14%
$ETM60$ + jet veto($p_T > 40\ GeV, \Delta\phi < 1.0$)	$5.5\ kHz$	14%	11%
$HTT70 + MHT/HTT > 0.7$	$9\ kHz$	22%	11%

The baseline trigger ETM70 give us 28% but we found 2 more trigger that will increase the yield of signal by at least 14%. Proposals from other groups do worst.

Baseline II

For now we will use L1T_ETM70 as seed and see if we can design a a good baseline HLT path on top.

- We need have a baseline HLT trigger HLT_PFMET170_NoiseCleaned
- Define additional HLT trigger with at most 5 *Hz* rate
- Define a prescaled control trigger (for systematics) with lower MET cuts.

HLT for Run 2

Again we run the grid search but for HLT variables

HLT Path	L1 Seed	Rate	Eff.	Total eff.
HLT_PFMET170_NoiseCleaned	L1_ETM70	-	9%	9%
HLT_DiPFJetVBF40_DEta3p5_MJJ600_PFMETNoMu140	L1_ETM70	4.7 *Hz*	-	10.5%
HLT_DiPFJetVBF60-40_DEta3p5_MJJ600_PFMETNoMu140	L1_ETM70	4.5 *Hz*	-	10.5%
Control trigger HLT_DiPFJetVBF40_DEta3p5_MJJ600_PFMETNoMu80	L1_ETM50	0.5 *Hz*	-	-

We have found 2 HLT paths that will increase signal yield by by over 25% using also L1_ETM70 as seed. This paths are now included on the menu for MC production and will be used for data recording (if not improved until then).

Summary:

- The starting point for any analysis is designing (or selecting) an appropriate trigger.
- Knowing the topology of your signal and detector/trigger capabilities is essential
- We were able to design a new baseline Run II trigger for VBF Higgs to Invisible which not only keep but increases signal efficiency compared with 2012.
- Studies are ongoing to improve baseline by reducing thresholds and adding extra conditions.