VBF Higgs Searches @ LHC-CMS

PhD 3 Months Report

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Introduction and Motivation

The current knowledge on the field of particle physics is summarized in the Standard Model. Its success comes from explaining a wide variety of experimental results.

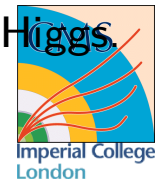
But still it is incomplete:

- Does not include the physics of dark energy or a full theory of gravity (like general relativity).
- Does not contain a dark matter candidate.
- Needs the inclusion of a spontaneous symmetry breaking mechanism to explain masses of the weak bosons:
  - The easiest way: Higgs Mechanism
  - Suggests: new particle the Higgs boson

After 2 years of operation the experiments at the LHC have:

- Narrowed down the allows mass range for the SM Higgs having excluded at 95% confidence level the range 127-600 GeV.
- Seen hits of a possible signal around 124 GeV (significance of 1.5σ after LEE).

Predicted running condition for 2012 will provide enough data to discover of exclude a SM Higgs.



SM Higgs Production Processes

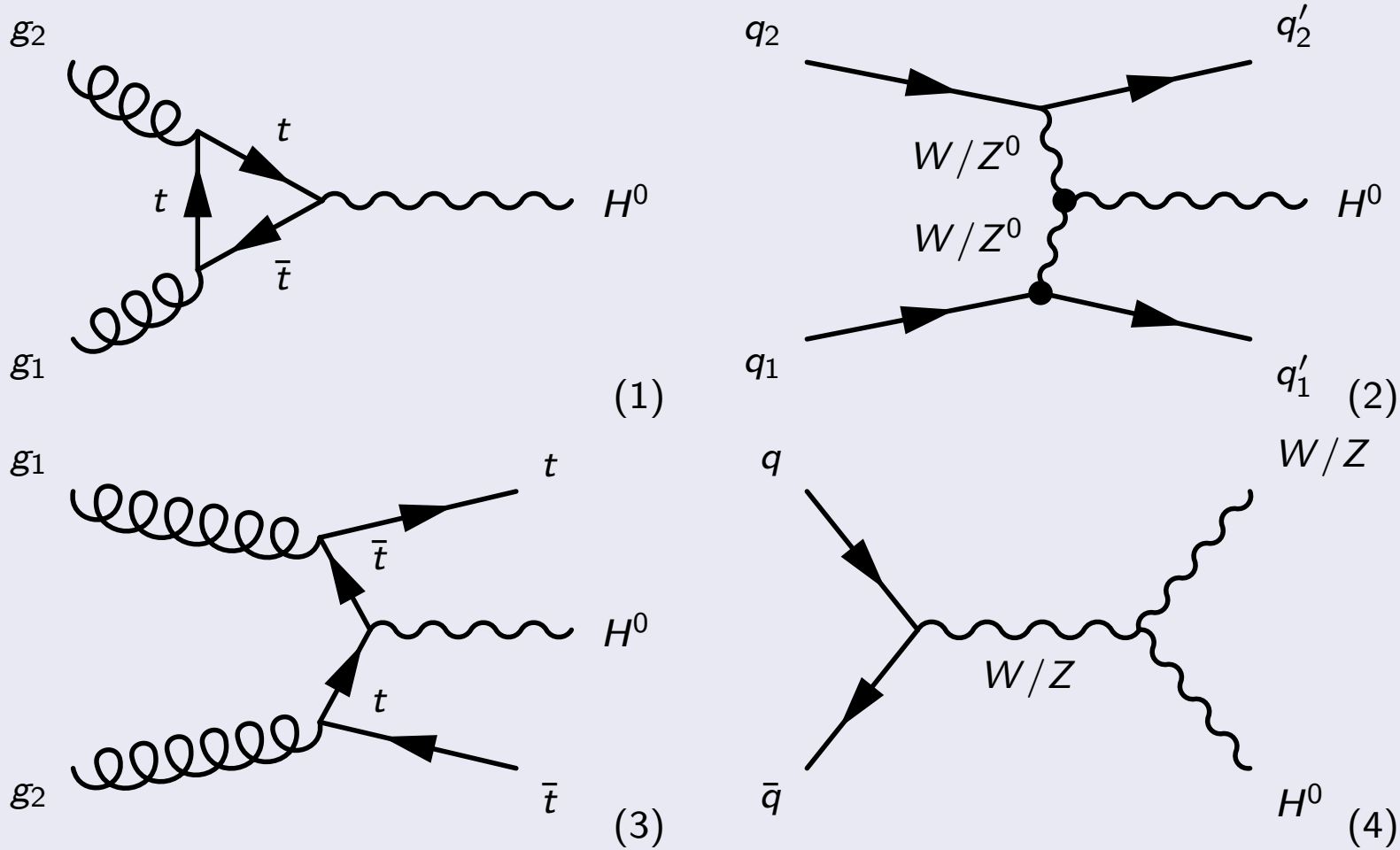
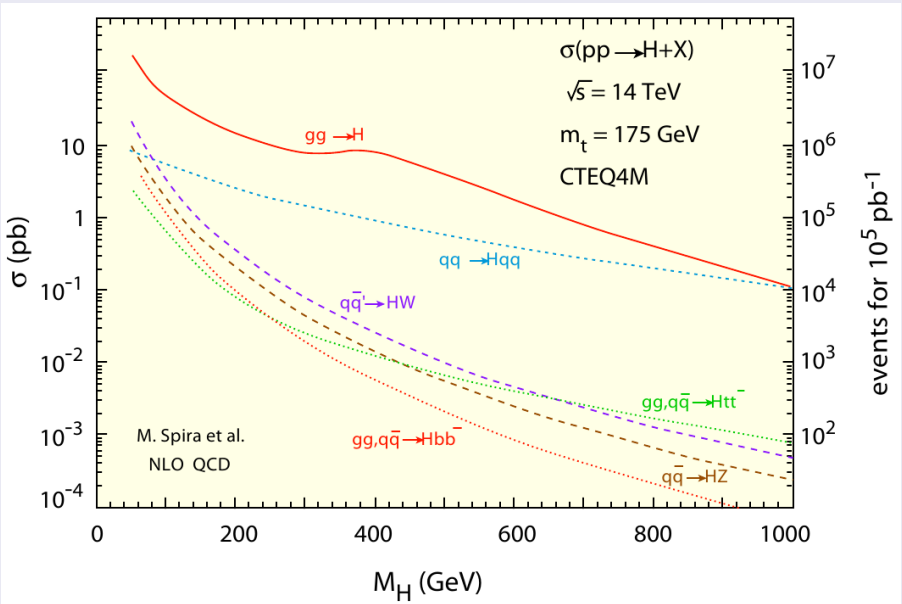


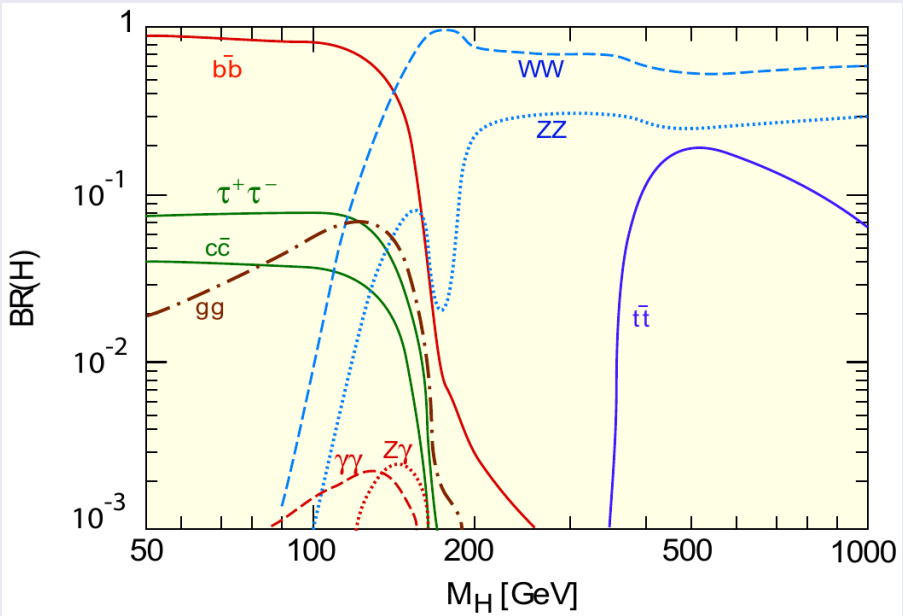
Table: SM Higgs production ordered by highest cross section at the LHC. (1) Gluon Fusion, (2) Vector Boson Fusion, (3) $t\bar{t}$ Fusion and (4) W/Z associated production.

Higgs Production Cross Section& Branching Ratio

SM Higgs Cross Section



Branching Ratio



For the currently allowed experimental mass range for the SM Higgs:

- VBF Signature is a factor of ~ 10 lower then gluon fusion.
- Most important/possible decays $b\bar{b}$, $\tau\bar{\tau}$, $c\bar{c}$, gg, $\gamma\gamma$ and $Z\gamma$.

Why VBF Higgs?

Theoretical

- Observe Higgs on this channel and measure its cross section and branching ratios for each decay.
- Measure Higgs coupling with Weak Bosons and fermions.
  - Higgs properties.
  - Differentiate between SM Higgs and BSM Higgs.
- Primary channel for discovery if Higgs only decays invisibly.

Experimental

VBF cross section is one order of magnitude lower than gluon fusion, but:

- Two additional Forward Jets (can be used for tagging).
- Low hadronic activity in central region (no colour exchange between quarks).
- Higgs decay products (channel dependent) are isolated in central area, allowing easier properties studies.

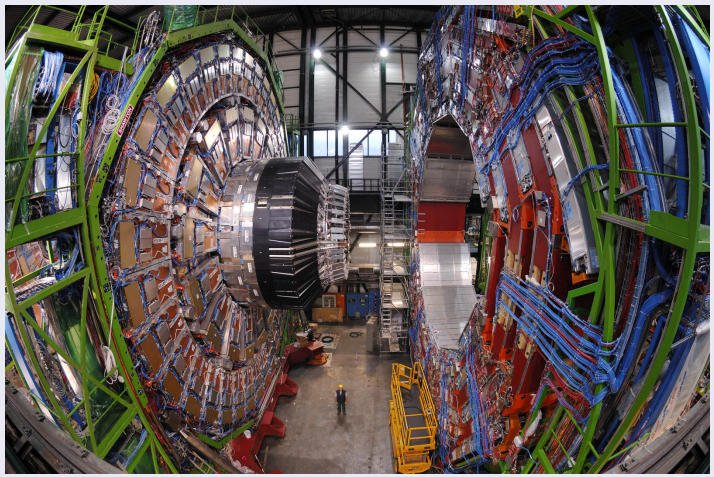
The LHC-CMS Experiment

Large Hadron Collider

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

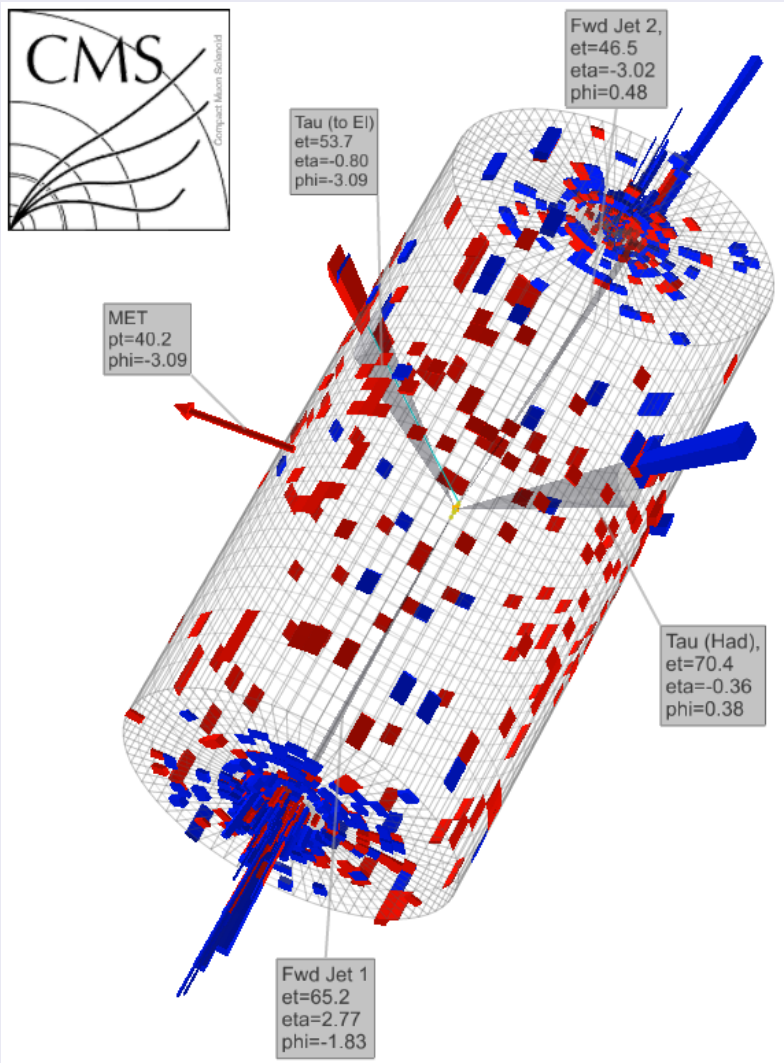
Compact Muon Solenoid

- Located at LHC Point 5.
- General purpose experiment.
- Objective of studying a broad spectrum of physics.
- Classical onion structure.
- Most powerful solenoid ever built (3.8 T).



VBF Signature @ CMS

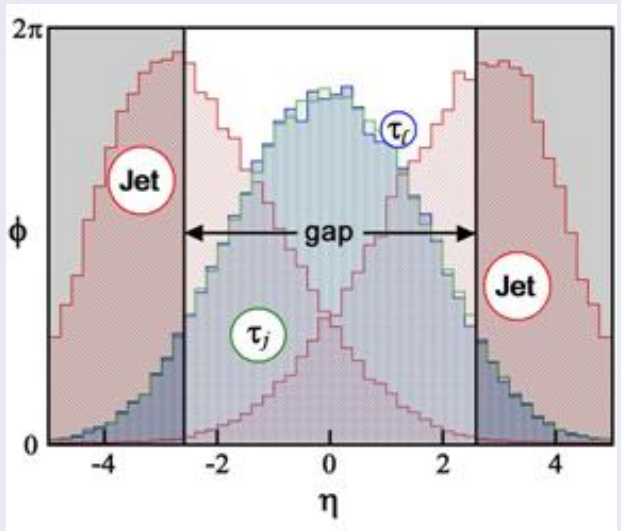
VBF $H^0 \rightarrow \tau\tau$ simulated event



Topology

- Two forward jet with resonable p_T
  - High $\Delta\eta$ and low $\Delta\phi$.
  - Low hadronic activity between jets (no color exchange between quarks).
  - High dijet invariant mass.
  - Higgs decay products on oposite direction of the dijet (signature specif)
- Additional Higgs Decay products signature.

Objects η distribution



Work and Plans

Current and finished work

- L1 Rates Study for the VBF Higgs to invisible study (finished, to be revisited)
- Development of dedicated Inclusive L1 Trigger (ongoing)

Plans

- Participate on the L1-HLT Inclusive VBF Trigger development, commissioning and maintenance.
- Develop a data analysis based on a VBF Higgs Channel aimed at observation and properties measurement.
- Participate on the trigger related effort (DQM, upgrades,...).

Rate Studies for a Higgs to Invisible L1 Trigger

Final resulst for this L1 rates study. Always requiring a dijet with $\Delta\eta > 3$ and testing each variable on 4 $\Delta\phi$ points (no cut, < 2.5, < 2.1 and < 1.8).

5e33 - $< PU >= 28$

MET [GeV] (with Dijet $E_\perp > 20$ [GeV])				
$\Delta\phi$	no cut	2.5	2.1	1.8
10kHz	32	32	32	32
5kHz	35	35	35	35
2kHz	41	41	41	41
1kHz	47	47	47	46
500Hz	54	54	54	53

Dijet $E_\perp$ [GeV] (with $MET > 30$ [GeV])				
$\Delta\phi$	no cut	2.5	2.1	1.8
10kHz	28	28	24	24
5kHz	32	32	32	32
2kHz	52	48	44	44
1kHz	68	68	64	64
500Hz	92	92	88	88

Results used to define the working point for this trigger, which was already proposed to the TSG to be included on a future L1 Trigger menus. Proposed trigger:

- Dijet $E_\perp > 20$ GeV + fwd/bkwd + $\Delta\eta_{jj} > 3$ + $MET > 40$ GeV
- Dijet $E_\perp > 50$ GeV + fwd/bkwd + $\Delta\eta_{jj} > 3$ + $MET > 30$ GeV

7e33 - $< PU >= 32$

MET [GeV] (with Dijet $p_\perp > 20$ [GeV])				
$\Delta\phi$	no cut	2.5	2.1	1.8
10kHz	36	36	36	36
5kHz	40	40	40	40
2kHz	47	47	47	46
1kHz	54	54	54	54
500Hz	67	66	66	64

Dijet $p_\perp$ [GeV] (with $MET > 30$ [GeV])				
$\Delta\phi$	no cut	2.5	2.1	1.8
10kHz	32	32	32	32
5kHz	40	40	40	40
2kHz	64	60	60	56
1kHz	76	76	76	76
500Hz	100	100	96	92

Development of dedicated Inclusive L1 Trigger

It would be desirable to have a dedicated Inclusive L1 Trigger (i.e. Higgs decay independent):

- Single trigger for all VBF signature analysis
  - Less systematics comparing analysis
  - More people using a trigger usually means it will become better understood
- No dependence in the Higgs decay
  - Get all possible decays (thus a Model Independent trigger)
- Can be used for a WW scattering analysis.

Trigger would be based only on the forward dijet present on the VBF signature

Types of trigger studied

Always requiring a dijet with $\Delta\eta > 3$ and testing each variable on 4 $\Delta\phi$ points (no cut, < 2.5, < 2.1 and < 1.8).

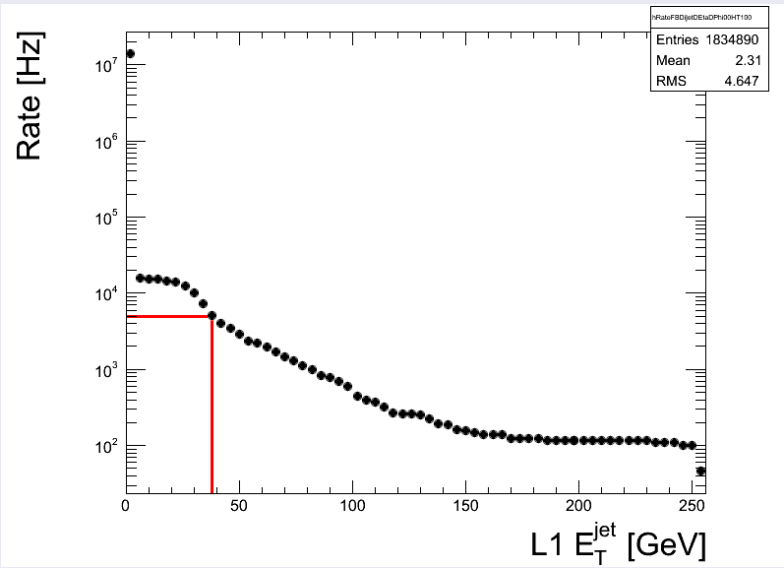
- Invariant Mass
  - Benefit from the very high M_{inv} of the dijet system.
  - Not yet implemented on the L1 Hardware but possible.
- Transverse Invariant Mass
  - Better suppression of QCD, less PU dependency and lower error associated (only x-y dependence).
  - Not yet implemented on the L1 Hardware but possible.
- HT (Vectorial Sum of the Hadronic Energy)
  - Theoretically best variable to separate signal from background.
  - Already implemented on L1 Hardware.

Results

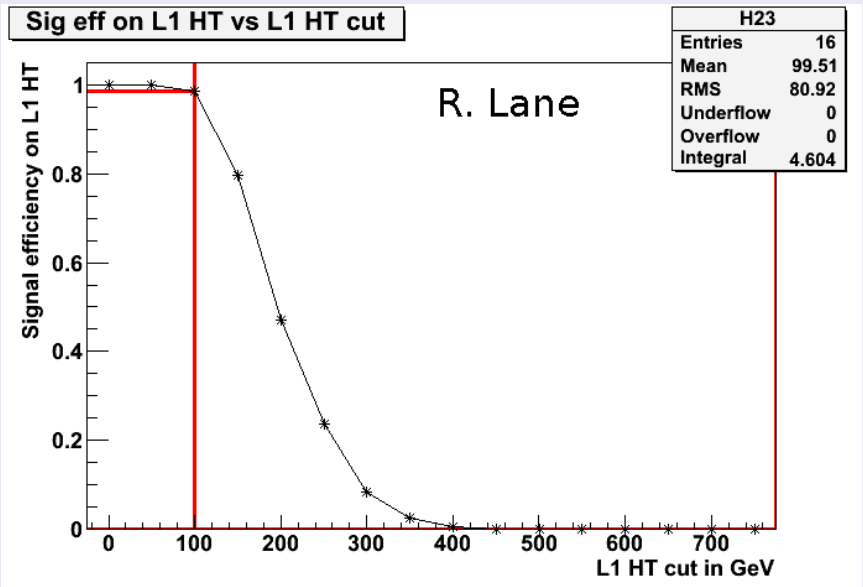
Trigger types:

- M_{Inv}: Unusable. To get acceptable rates have to cut too high on Jet $p_\perp$ or M_{Inv} losing signal efficiency.
- $M_\perp$: Promising. Rate of 5kHz with $MT > 50GeV$ no $\Delta\phi$ cut and dijet $p_\perp \sim 45GeV$ giving a signal efficiency of $\lesssim 70\%$ (see R. Lane talk)
- HT: Most promising. Rate of 5kHz with $HT > 100GeV$ no $\Delta\phi$ cut and dijet $p_\perp \sim 40GeV$ giving a signal efficiency of $\lesssim 98\%$ (see R. Lane talk)

Rate(dijet $p_\perp$) for $HT > 100GeV$



HT efficiency



Conclusions

Overview

- There will be a VBF Higgs to Invisible dedicated trigger for 2012.
- Most likely an inclusive VBF trigger will be included soon, which should cover most of the 2012 data.
- 2012 will be an exciting year for all the LHC experiments.
- Imperial College CMS Group highly involved on the trigger effort for VBF analysis.
  - Which will evolve quickly with data to a full analysis effort aimed at publication of the (soon to be discovered) Higgs Boson properties.