



# The CMS Level-1 Vector Boson Fusion trigger for the LHC Run II

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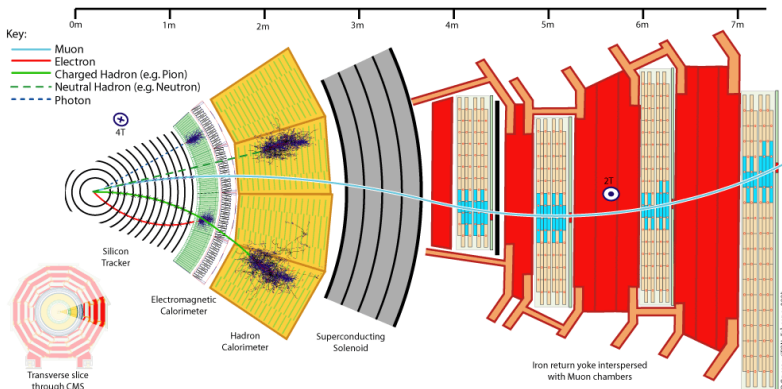
*November 27, 2017*

# CMS: Compact Muon Solenoid

## (Large Hadron Collider - CERN, Geneva)

General purpose experiment

- Higgs physics, Standard Model precision measurements, physics beyond the Standard Model...
- currently collecting  $\sqrt{s} = 13$  TeV proton-proton collisions
- each subdetector is dedicated to a different task





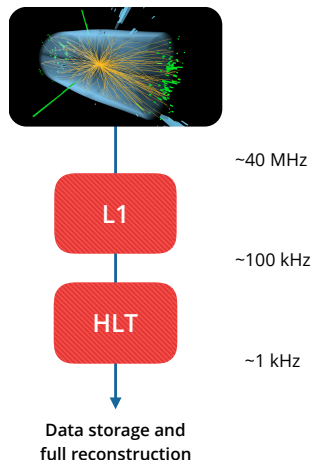
# The CMS Trigger System

Storing everything is not sustainable:

- bunch crossing rate:  **$\sim 40$  MHz**
- sustainable event output rate:  $\sim 1$  kHz
- data storage throughput rate:  $\sim 3$  Gb/s

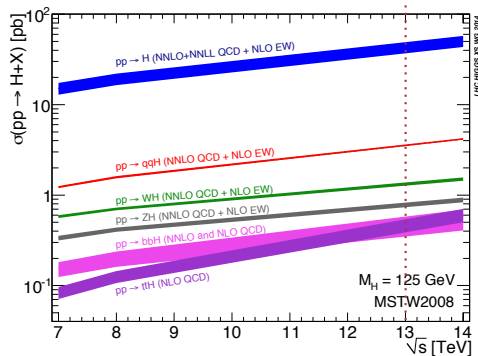
Two-level trigger to make a fast selection:

- **Level-1 Trigger**
  - only calorimeters and muon chambers, only  $\sim 3.8 \mu\text{s}$  to take a decision
- **High Level Trigger**
  - exploits the full detector information, takes a decision in  $\sim 200$  ms



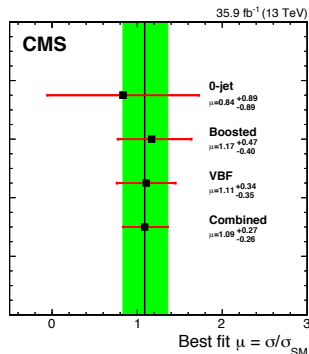
# A trigger for the Vector Boson Fusion process

g-g Fusion: dominant process,  $\sim 50$  pb

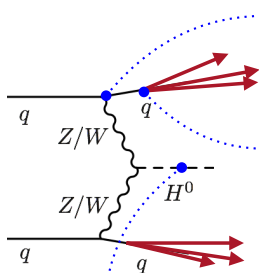


Vector Boson Fusion:  $\sim 4$  pb  
 $\sim 10\%$  of the total Higgs boson production

- The signature of the process is very characteristic
- excellent signal to background ratio
- The VBF category is one of the most sensitive for  $H \rightarrow \tau\tau$



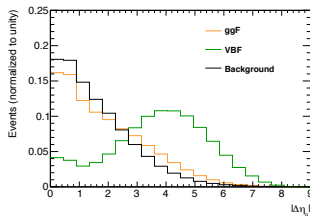
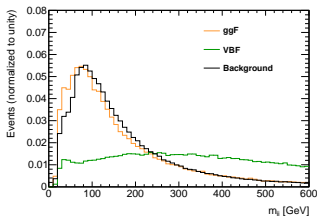
# The VBF process



within the  $p$ - $p$  interaction, the involved quarks can emit vector bosons, losing a small amount of their longitudinal energy

the hadronization of a quark or gluon results in **jets** (tens of particles collimated in the direction of the original quark/gluon): the VBF jet pair has **large invariant mass** and **large angular separation**

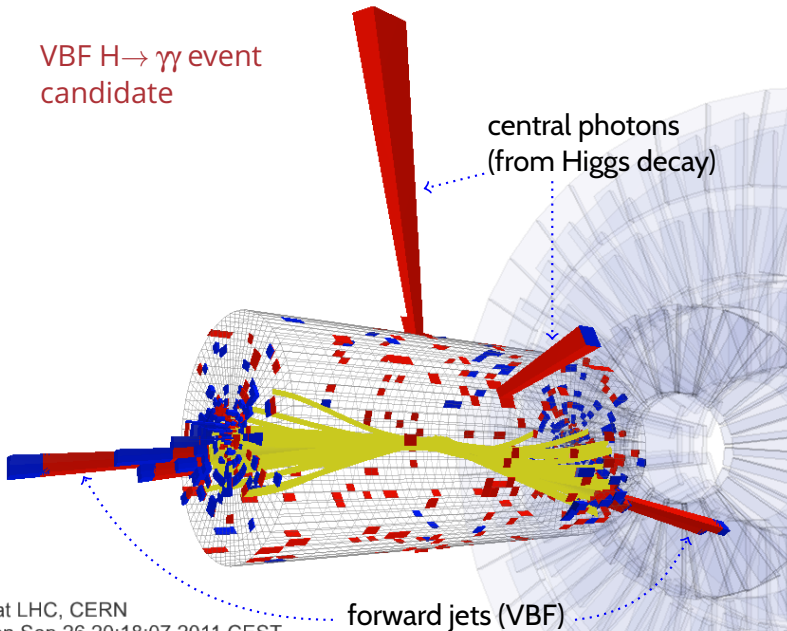
the Higgs boson decay products are usually in the central region of the detector





VBF  $H \rightarrow \gamma\gamma$  event  
candidate

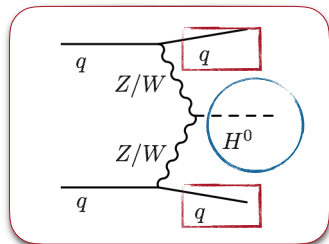
central photons  
(from Higgs decay)



forward jets (VBF)

CMS Experiment at LHC, CERN  
Data recorded: Mon Sep 26 20:18:07 2011 CEST  
Run/Event: 177201 / 625786854  
Lumi section: 450

# The VBF trigger strategy



The usual trigger strategies target the **decay mode**, while in this case the selection is specific for the **production mode**

Recent upgrade of the L1 trigger system: complex correlations (e.g. invariant mass) can be computed

**L1 trigger selection for VBF production:**

- at least one jet with  $E_T > X$
- at least two jets with  $E_T > Y$
- in the collection of jets with  $E_T > Y$ , at least a pair with  $m_{jj} > Z$

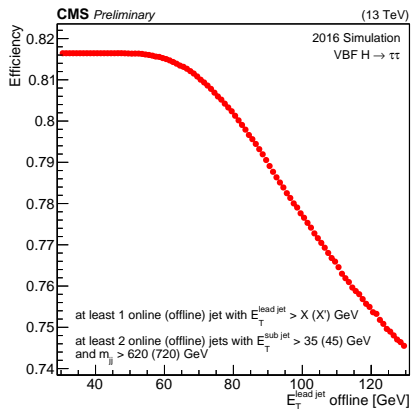
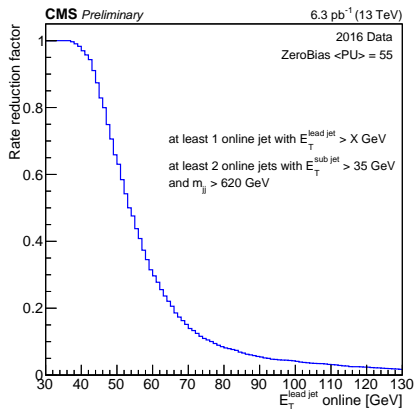
The VBF trigger is meant to be a complement to classic triggers

- e.g. the  $H \rightarrow \tau\tau$  analysis relies on a dedicated hadronic  $\tau$  trigger, selecting  $\tau$  pairs with  $E_T > 32$  GeV

# Trigger optimisation

In order to choose the thresholds, two factors of merit are considered:

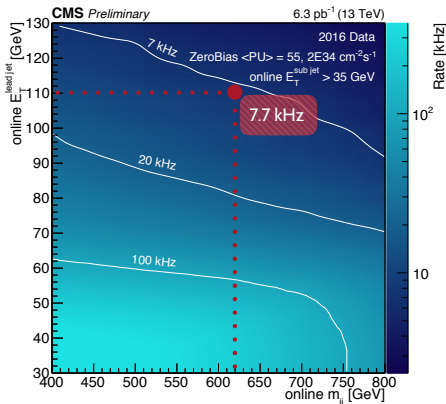
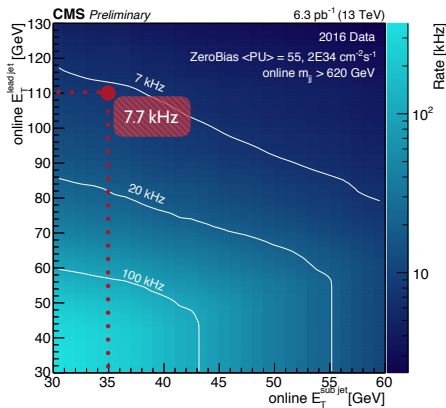
- **high rate reduction** in order to fit in the available L1 rate, shared with the other L1 selections
- **high efficiency** because any event not selected at L1 is lost!



# Rate estimation

Rate estimated from the fraction of events that passed the selection with each set of thresholds

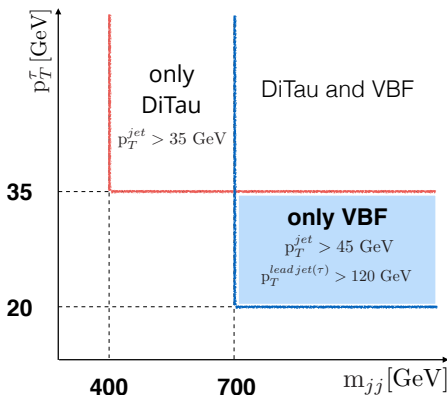
- leading jet:  $E_T > 110$  GeV
- subleading jets:  $E_T > 35$  GeV,  $m_{jj} > 620$  GeV



only 2.5 kHz of additional rate with respect to the full L1 selection

# Comparison with $\tau$ -pair trigger

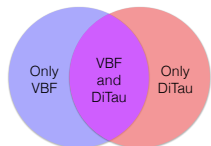
Is there some gain brought by using VBF **and**  $\tau$ -pair trigger rather than  $\tau$ -pair trigger alone?



In order to compare, realistic analysis-like scenarios are reproduced

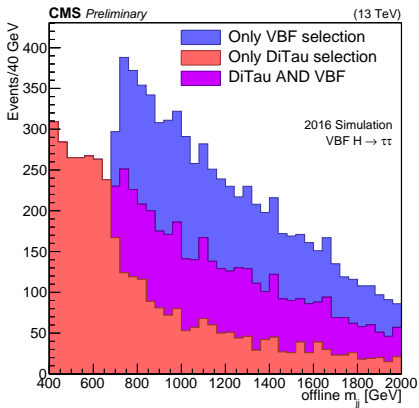
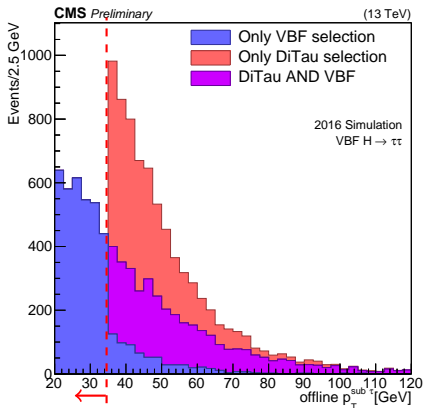
- for each of the triggers, a corresponding suitable offline selection is chosen
- categories of events are defined
- the gain is estimated from the event yield in each category

# Event yield gain



Large event yield gain by extending the phase-space coverage:

$$\frac{N_{\text{onlyVBF}}}{N_{\text{DiTau}}} = 58\%$$



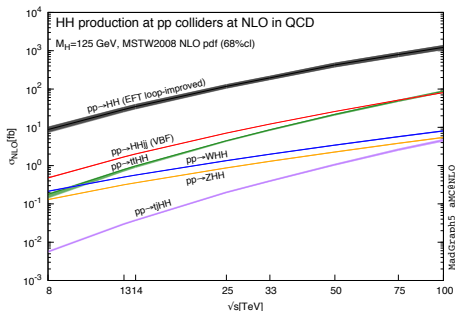
# Perspectives

- the VBF trigger is implemented in the L1 selection for 2017 data taking
- HLT level triggers developed on top of the VBF trigger are implemented as well
  - HLT VBF  $H \rightarrow \tau\tau$  trigger dedicated to  $H \rightarrow \tau\tau$
- the  $H \rightarrow \tau\tau$  was used as a physics benchmark, but the VBF trigger can be valid also for other H decay channels
  - it targets the production mode: for example it can be very useful for  $H \rightarrow \text{invisible}$

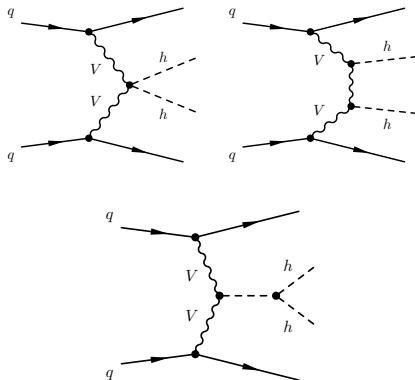
# VBF HH production

VBF HH production cross section is  $\sim 2$  fb at  $\sqrt{s} = 13$  TeV

- can profit of VBF having a very characteristic signature



([arXiv:1401.7340](https://arxiv.org/abs/1401.7340))



- the VBF trigger was found to bring a large gain also in VBF  $HH \rightarrow b\bar{b}\tau\tau$

# Conclusions

- the VBF production mode is subdominant, but it has a very clean signature
- the CMS L1 trigger system allows complex correlations between objects to be computed
  - many open possibilities: triggers can be analysis-targeted
- the VBF signature can be exploited starting from trigger level
  - this is the first trigger targeting the production mode
  - by using it as a complement of the classic triggers, the coverage of the phase-space is expanded
  - it brings a large event yield gain ( $\sim 58\%$ ) for VBF  $H \rightarrow \tau\tau$  signal