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

Chiara Amendola

Laboratoire Leprince-Ringuet

École polytechnique, Paris

PHENIICS Fest 2018

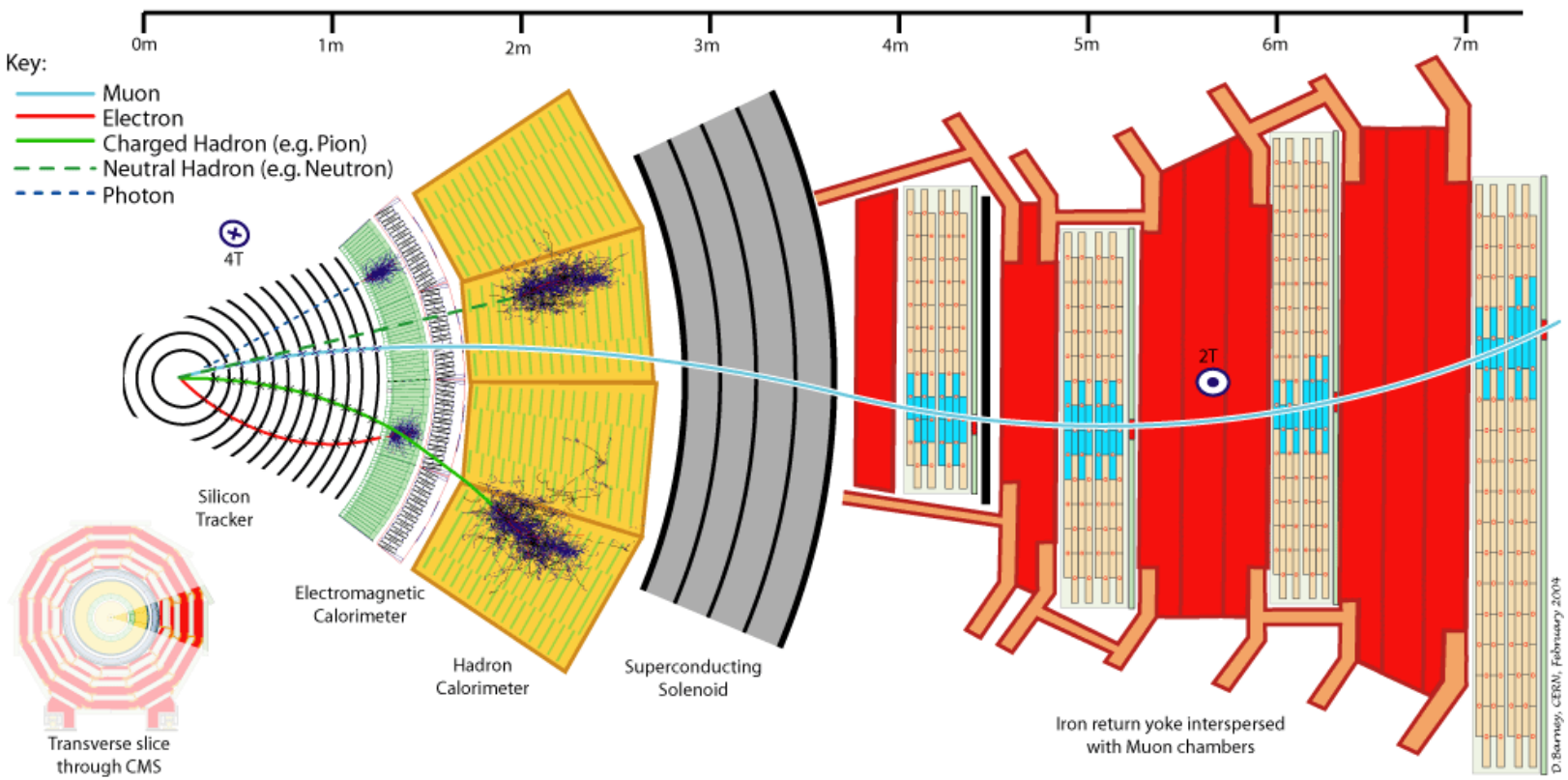
May 29, 2018

CMS: Compact Muon Solenoid

(*Large Hadron Collider* - CERN, Geneve)

General purpose experiment

- Higgs physics, Standard Model precision measurements, physics beyond the Standard Model...
- currently collecting $\sqrt{s} = 13$ TeV proton-proton collisions



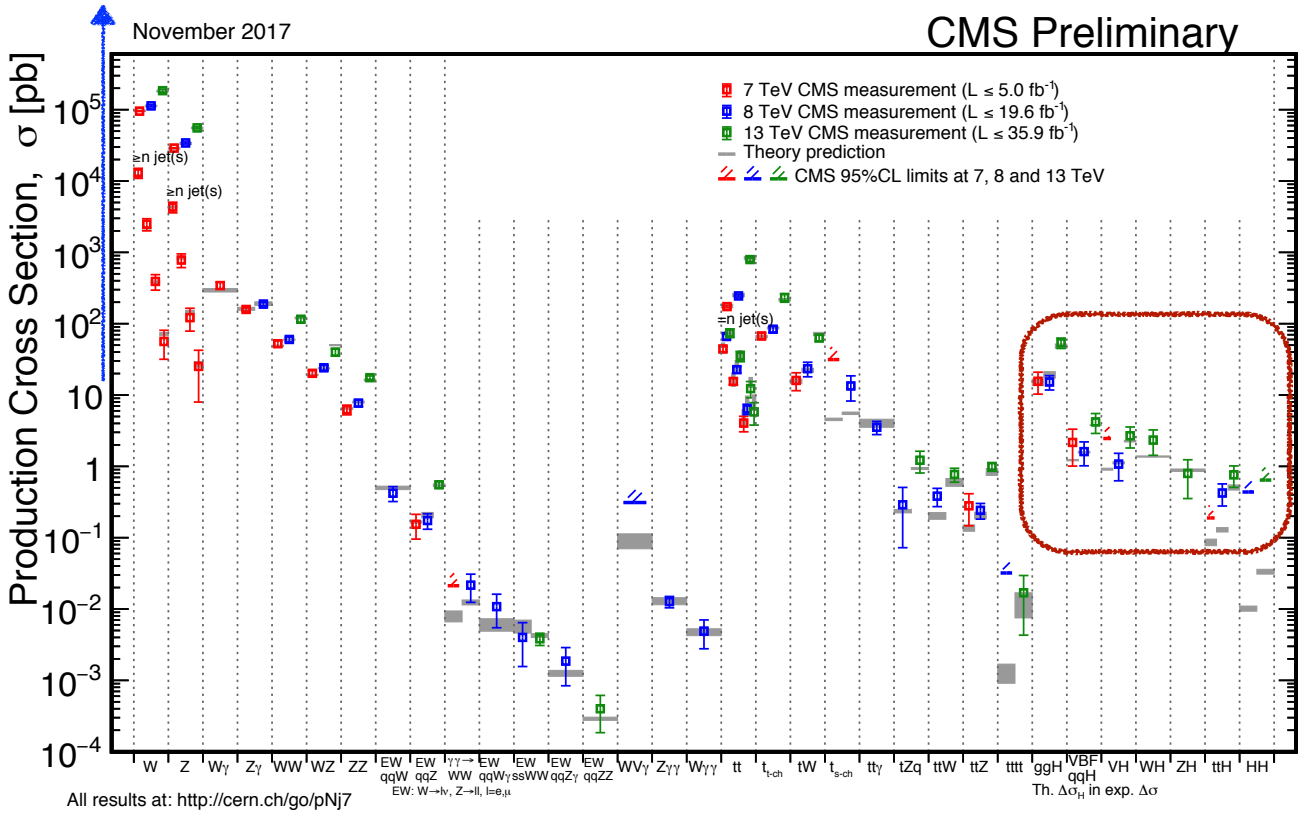
Why is a trigger system needed?

The number of events for a given process is given by its **cross section** and the **luminosity**

$$N_{evt} = \int \sigma \mathcal{L} \, dt$$

- $\sigma_{pp} \sim 70$ mb
- the cross section of interesting processes is much lower!

  e.g. VBF H$\rightarrow \tau\tau$: $\sigma \cdot BR$ = 0.23 pb



High luminosity compensates low cross section

- LHC operations in 2017: currently $\mathcal{L}$ went up to $2.2 \cdot 10^{34}$ cm^{-2}s^{-1}
- high luminosity $\rightarrow$ **high pile up**

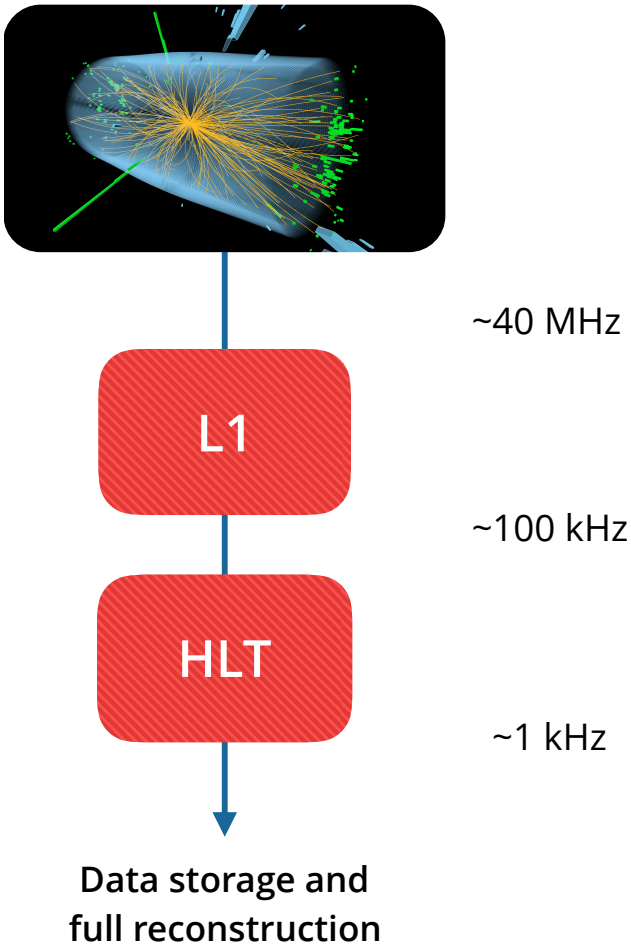
The CMS Trigger System

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:

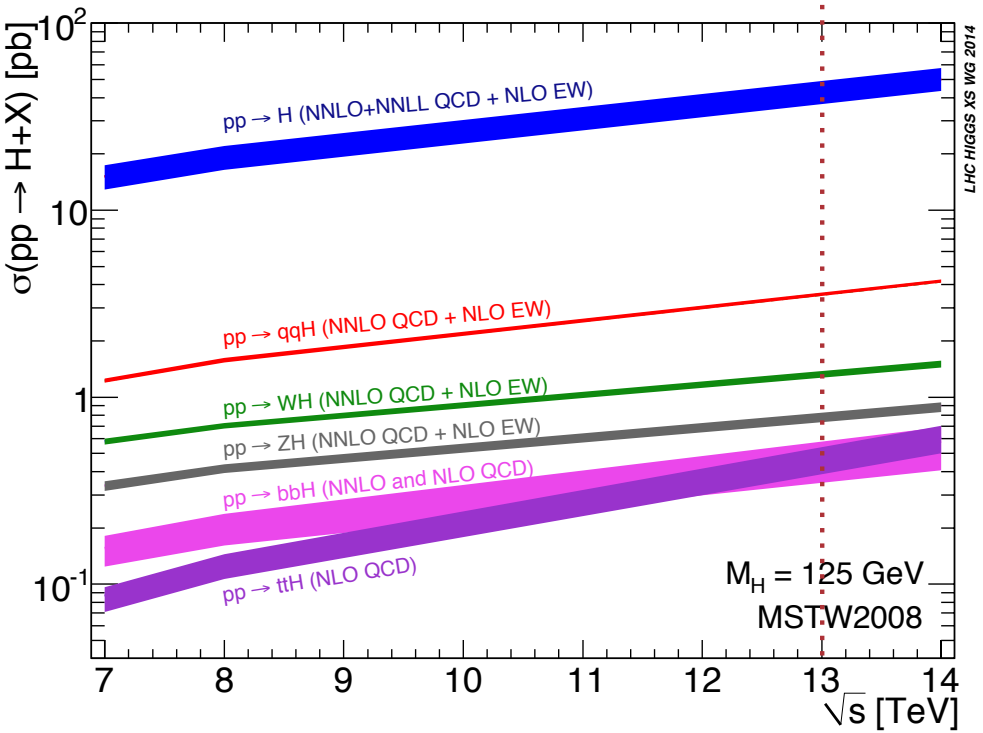
- **Level-1 Trigger**
  - using inputs only calorimeters and muon chambers, only $\sim$3.8 μs to take a decision
- **High Level Trigger**
  - exploits the full detector information, takes a decision in $\sim$ 200 ms



2015-2016: major L1 system upgrade installed and commissioned to face the challenging data taking condition of 2017

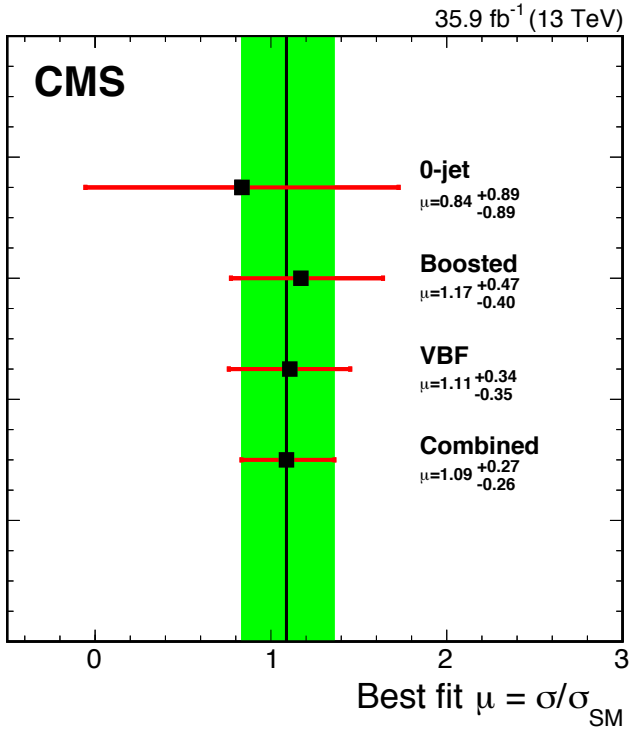
A trigger for the Vector Boson Fusion process

g-g Fusion: dominant process, ∼50 pb

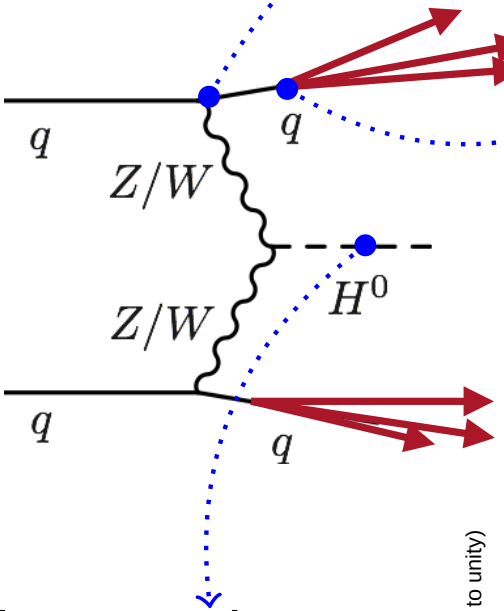


Vector Boson Fusion: ∼4 pb
∼10% of the total Higgs boson production

- The signature of the process is very characteristic
  - excellent signal to background ratio
- The VBF category is one of the most sensitive for H→ ττ



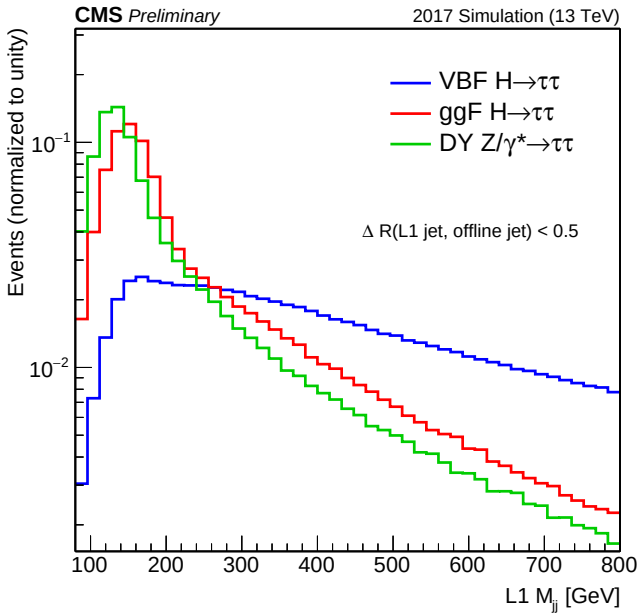
The VBF process

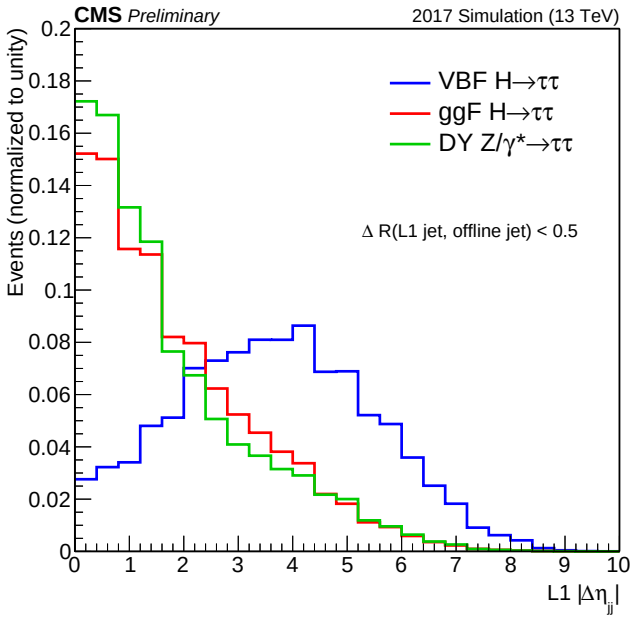


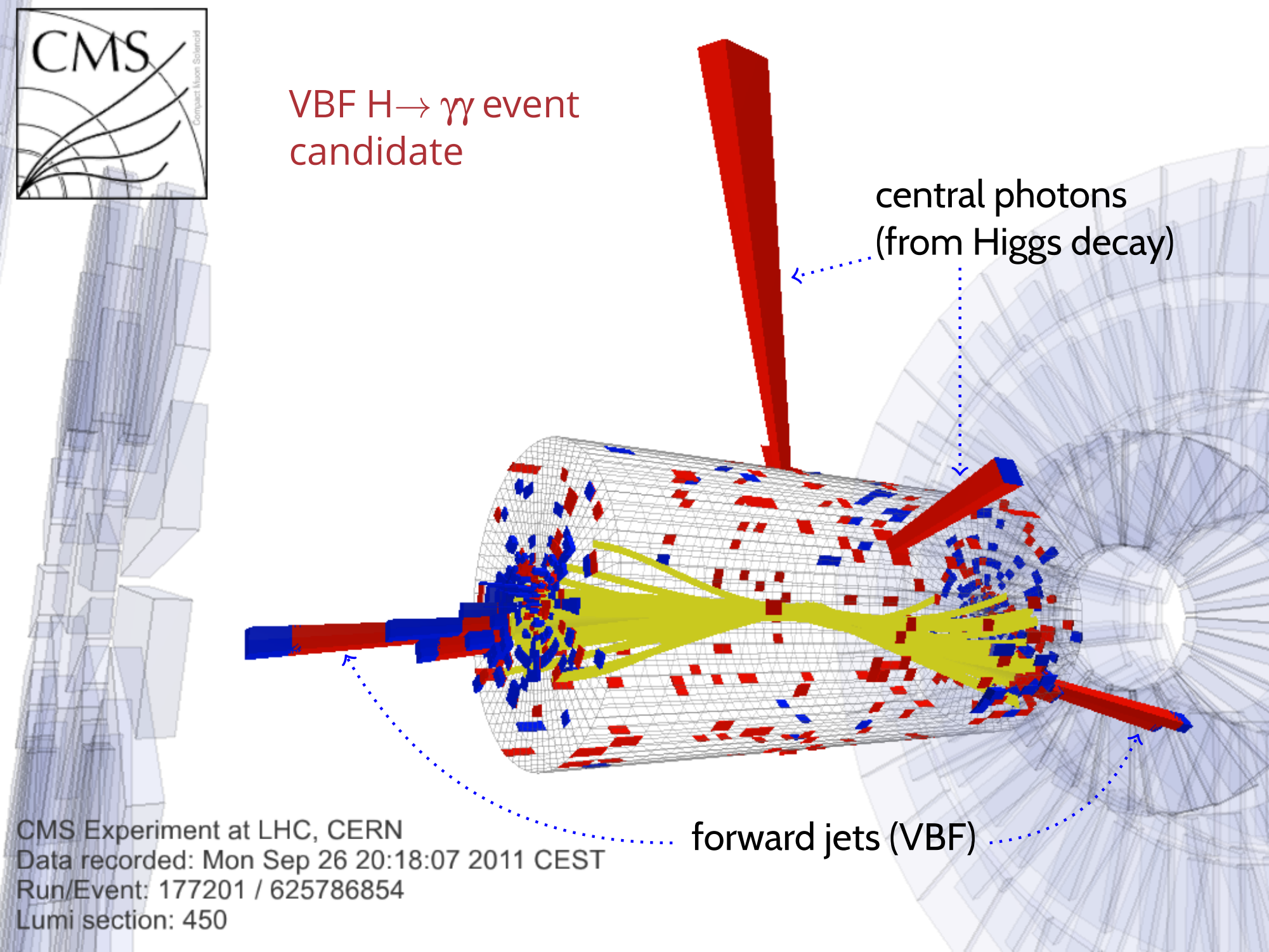
within the *p*-*p* interaction, the involved quarks can emit vector bosons, losing a small amount of their longitudinal energy

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**

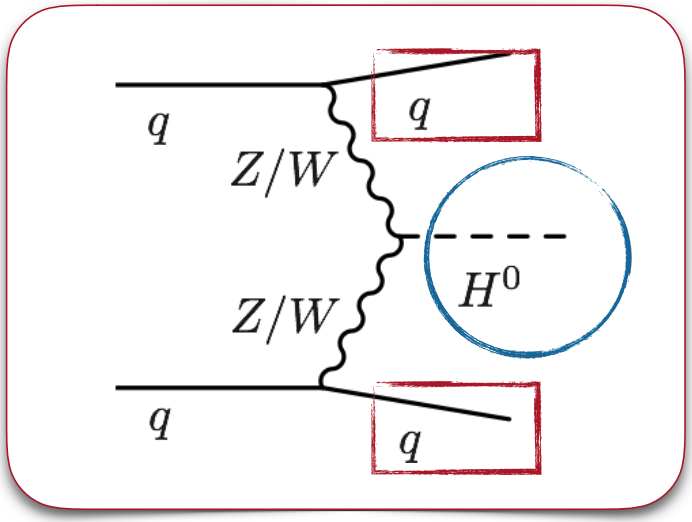
the Higgs boson decay products are usually in the central region of the detector






VBF H→ γγ 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**: using it as a complement to the classic triggers, **the phase-space is expanded** and the sensitivity to VBF is improved

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 $m_{jj} > Z$

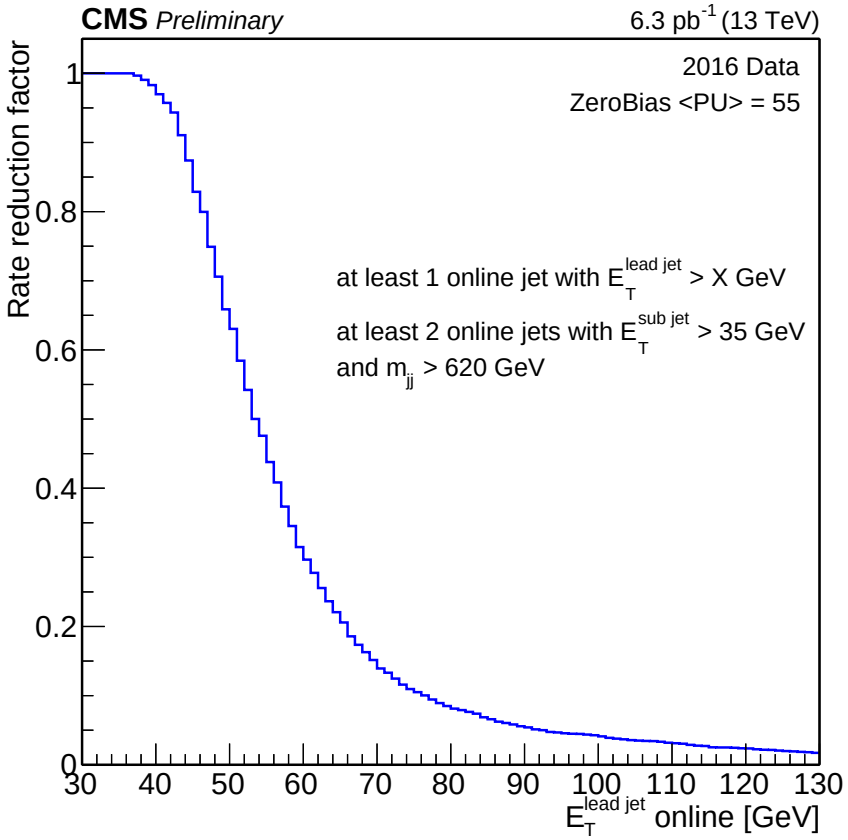
The VBF trigger is meant to be a complement to classic triggers

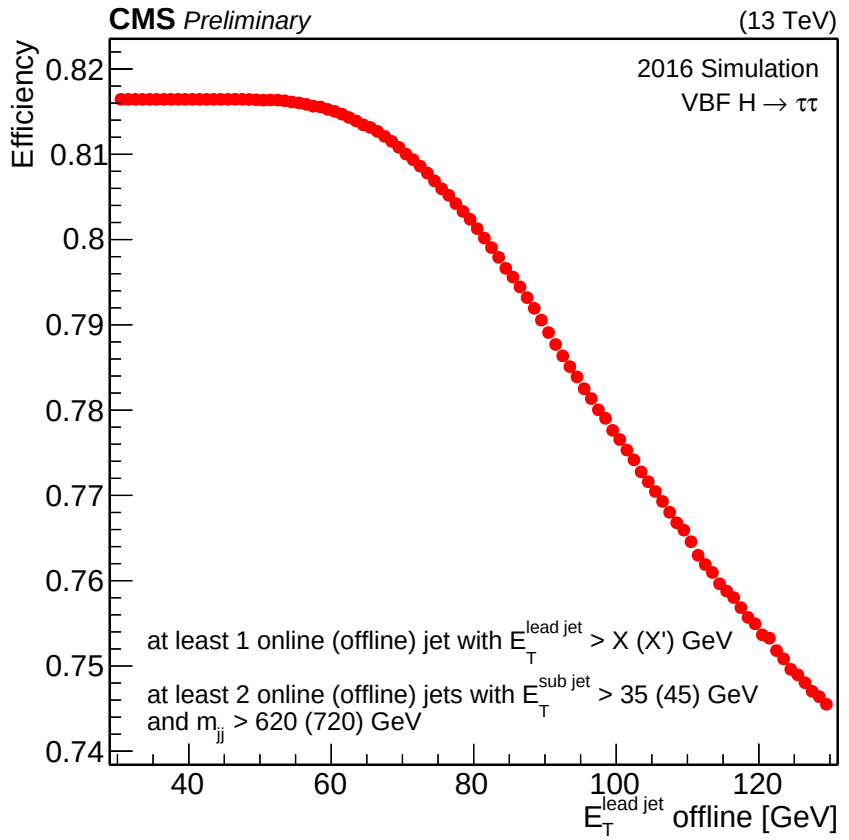
- e.g. the H$\rightarrow \tau\tau$ analysis relies on a dedicated hadronic τ trigger, selecting **τ pairs** with $E_T > 32$ GeV

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!

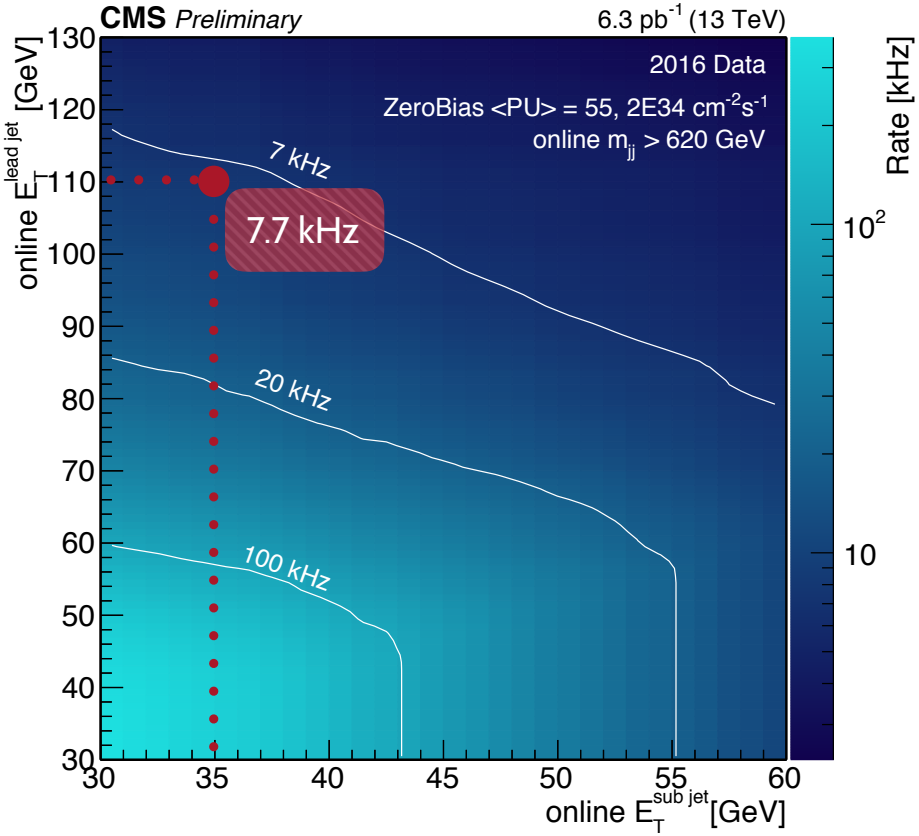


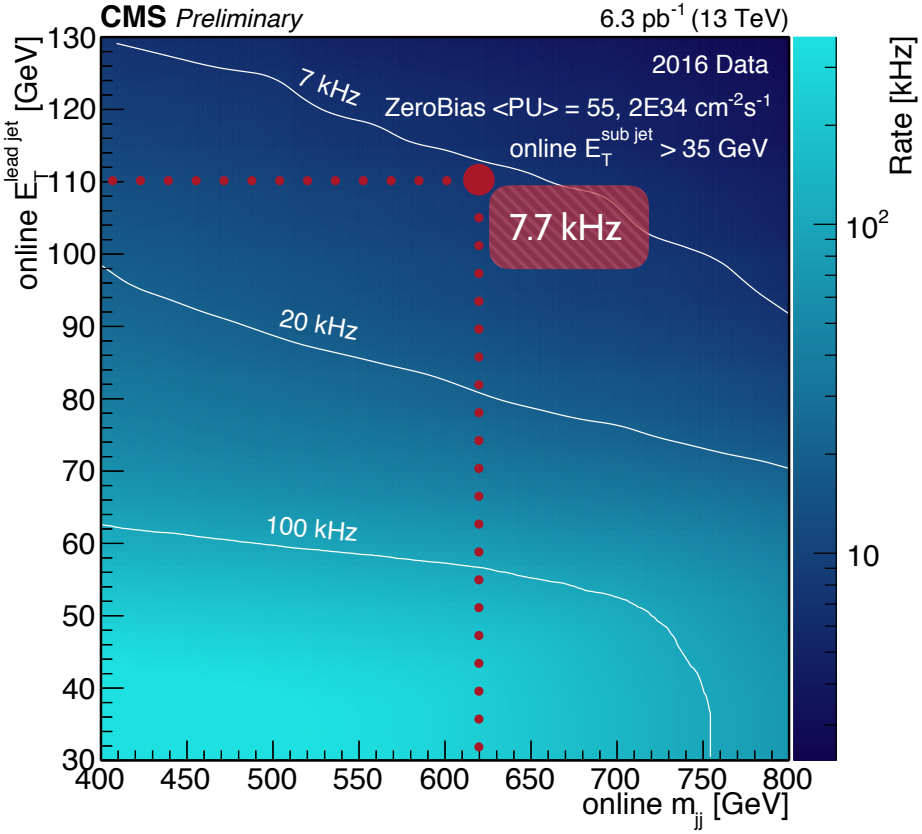


Rate estimation

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

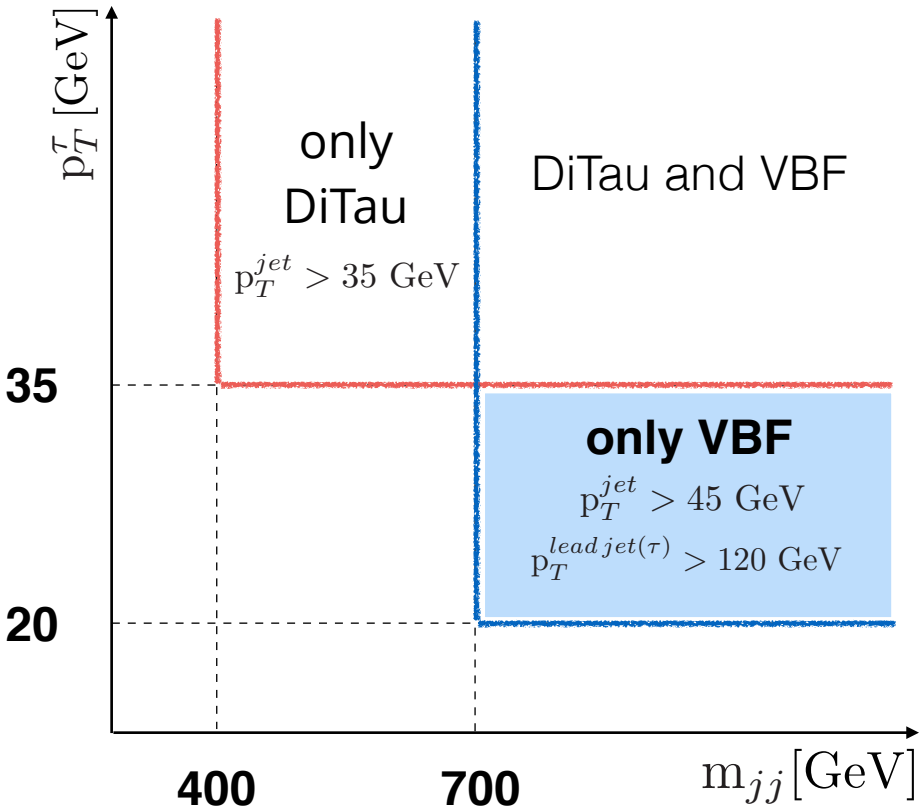




only 2.5 kHz of additional rate with respect to the full L1 selection

Comparison with τ-pair trigger

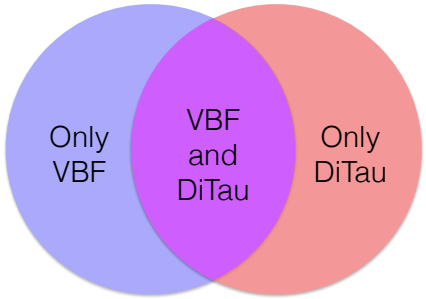
Is there some gain brought by using VBF and τ-pair trigger rather than τ-pair trigger alone?



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

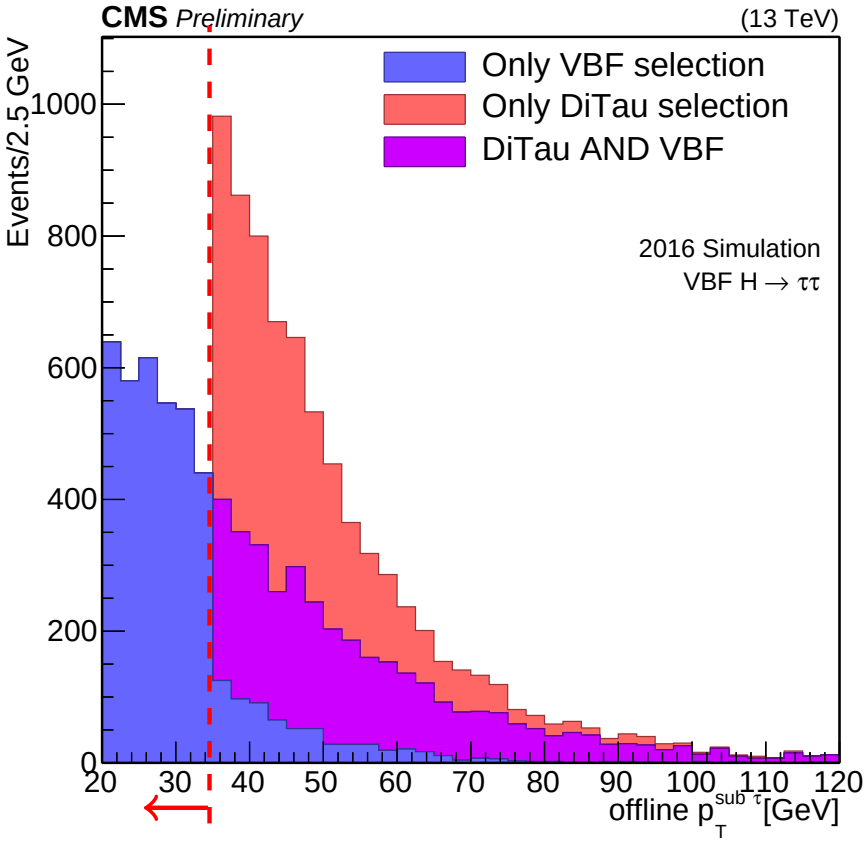
- for each of the triggers, a corresponding suitable offline selection is chosen
- categories of events are defined
- the gain is estimated from the event yield in each category

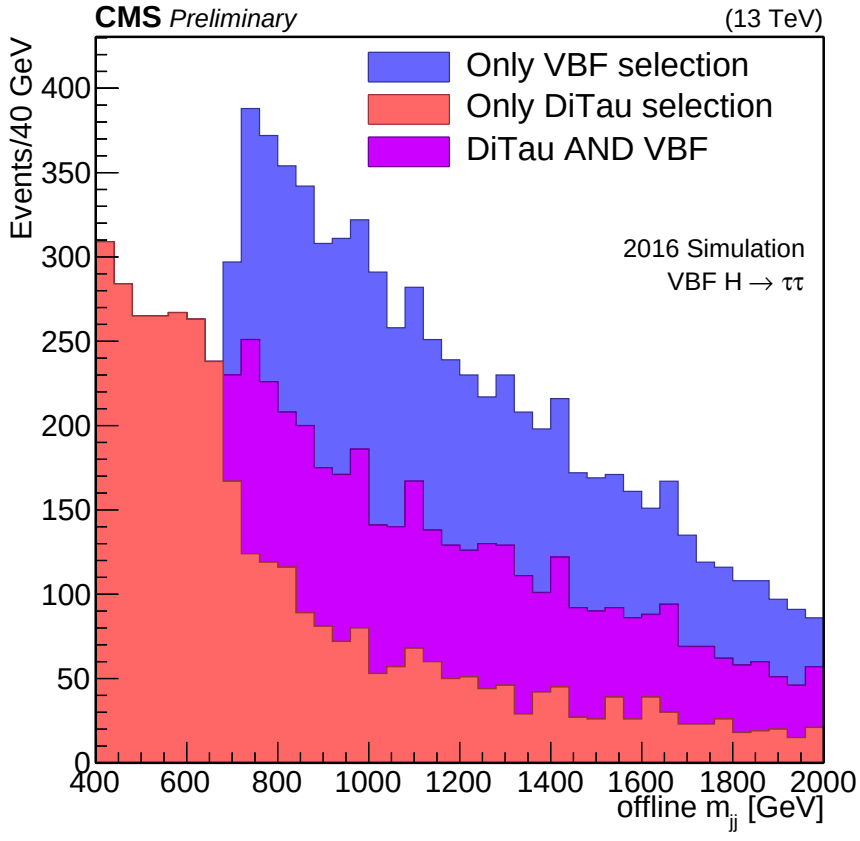
Event yield gain



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

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

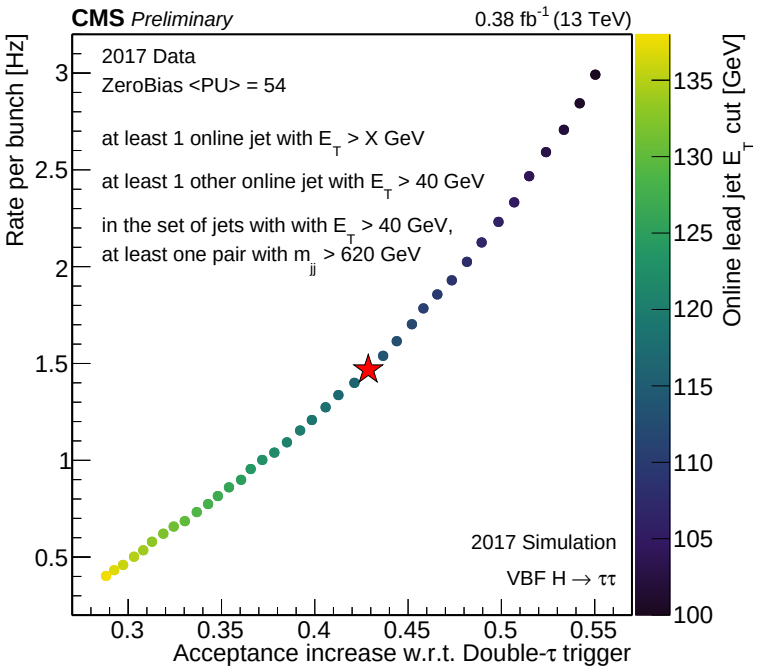




Performance

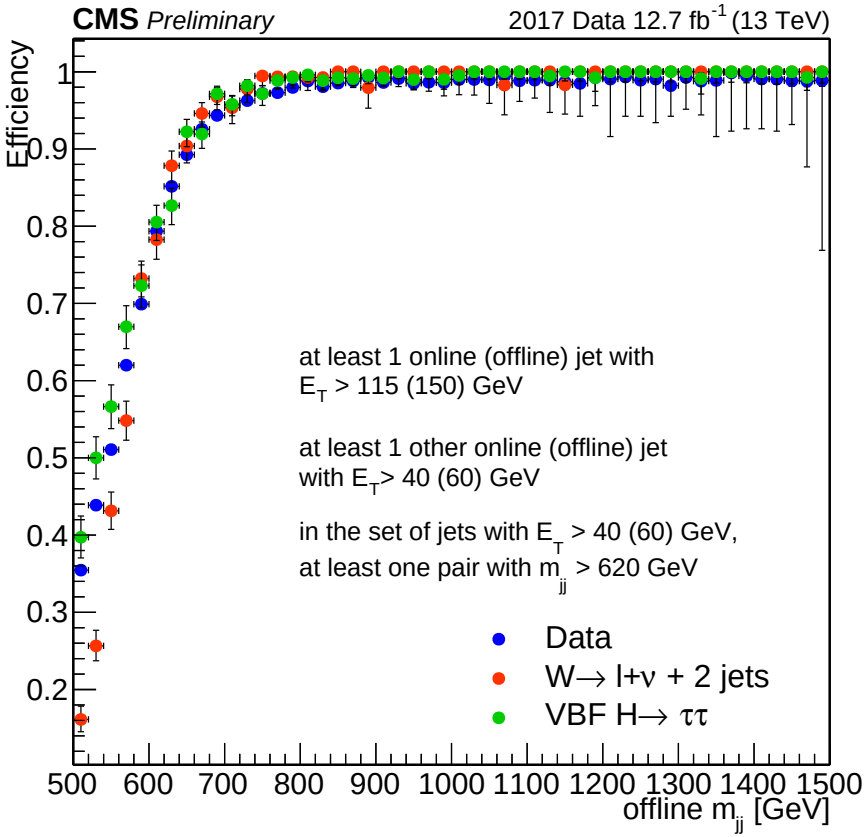
The VBF trigger was implemented in the L1 selection for data taking starting from 2017

- tuning the thresholds is a trade-off between rate reduction and efficiency



★ the $X = 115\ GeV$, $Y = 40\ GeV$, $Z = 620\ GeV$ L1 selection, online throughout 2017, provides $\sim$ **43%** additional VBF H$\rightarrow \tau\tau$ events

Eccellent efficiency



Perspectives

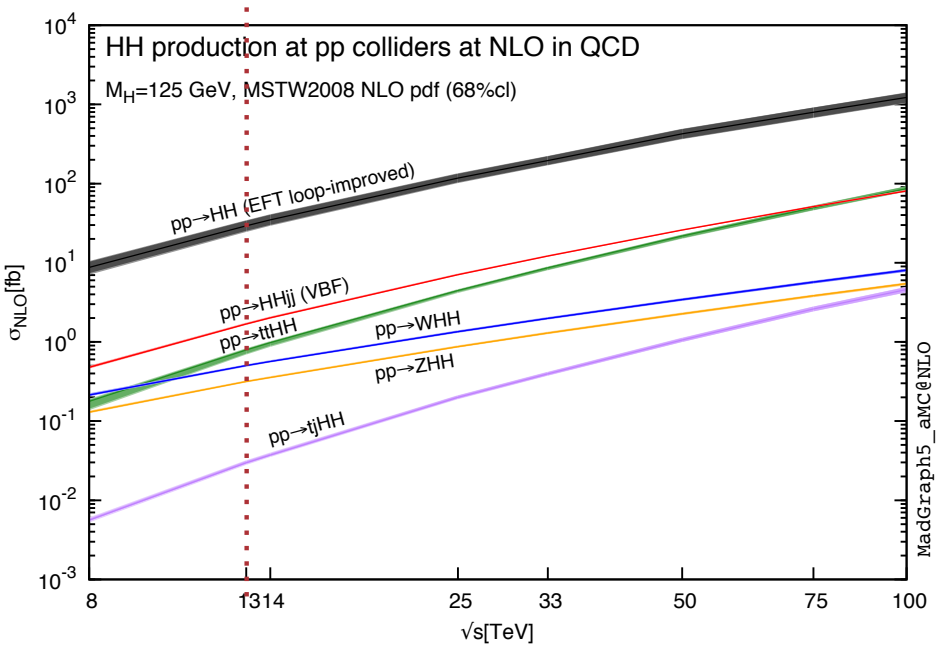
- HLT level triggers developed on top of the VBF trigger are implemented as well
  - HLT VBF H$\rightarrow \tau\tau$ trigger dedicated to H$\rightarrow \tau\tau$

- 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$\rightarrow$invisible

HH production

The measurement of $\sigma(HH)$ is sensitive to the trilinear Higgs coupling λ_3

- low cross section: $\sim$ 30 fb at $\sqrt{s} = 13$ TeV for the gluon-gluon Fusion process (dominant)
- $BR_{SM}(\mathrm{HH} \to \mathrm{bb}\tau\tau) \sim 7\%$: good compromise between selection efficiency and signal purity

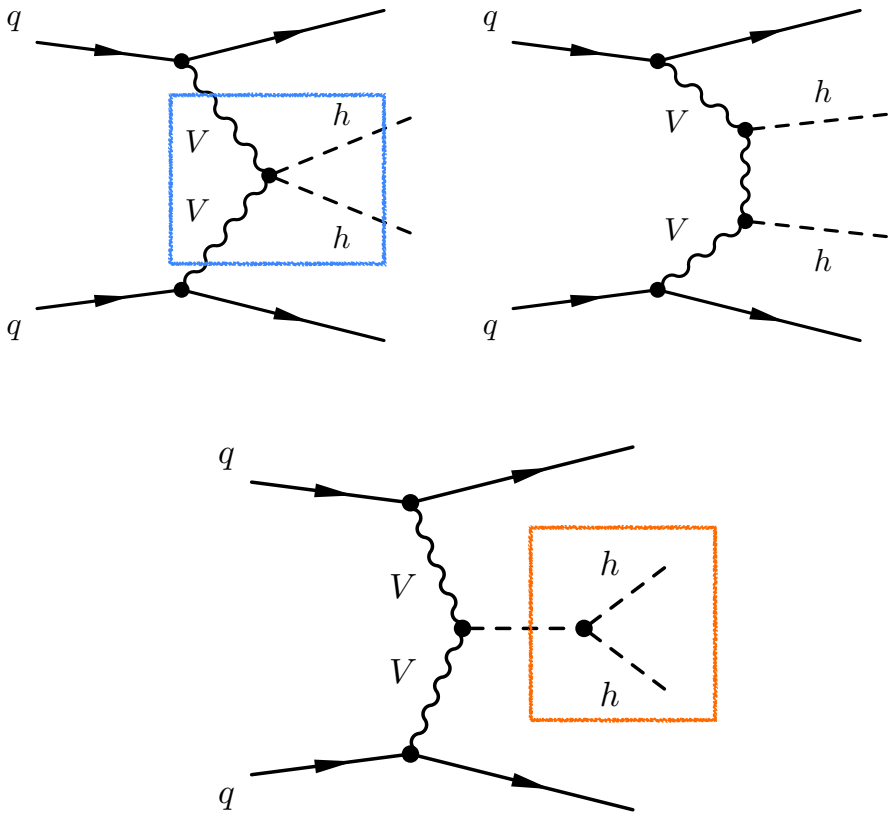


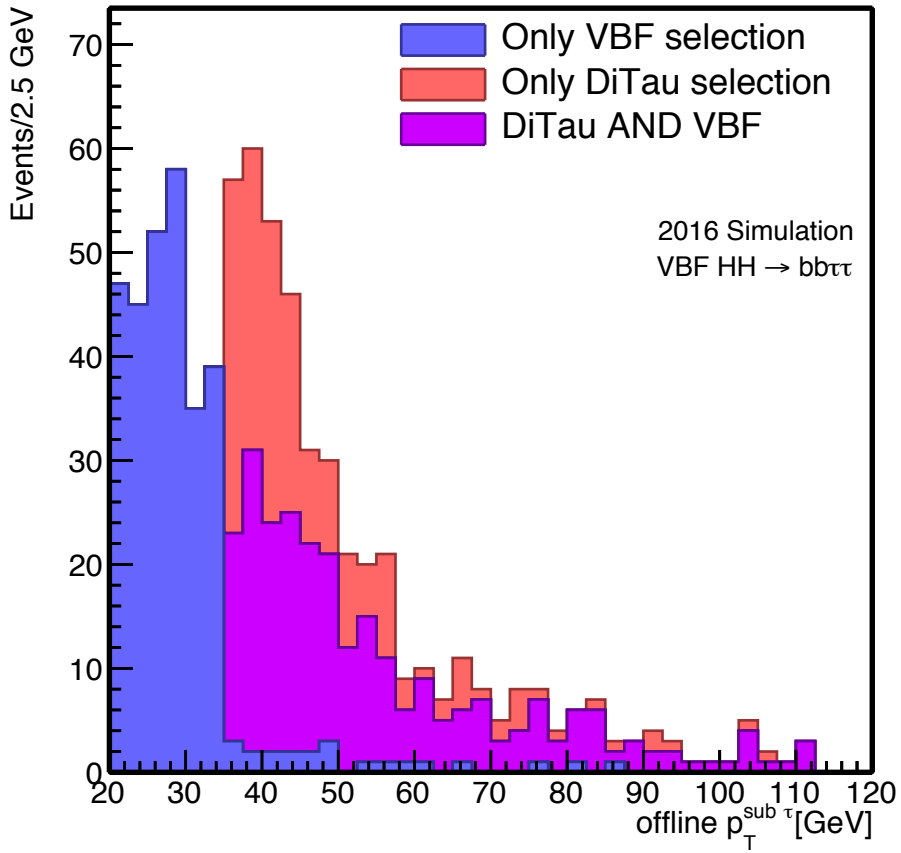
The VBF HH production cross section is $\sim$ 2 fb at $\sqrt{s} = 13$ TeV, but

- can profit of VBF having a very characteristic signature
- if the channel $\mathrm{H} \to \tau\tau$ is involved, it can benefit from the brand new VBF trigger

VBF category for HH→ bbττ

- different production modes have different sensitivity to λ_3
- in addition to λ_3, can constrain λ_{2V}





Large event yield gain brought by the VBF trigger:

$$\frac{N_{onlyVBF}}{N_{DiTau}} \sim 70\%$$

Conclusion

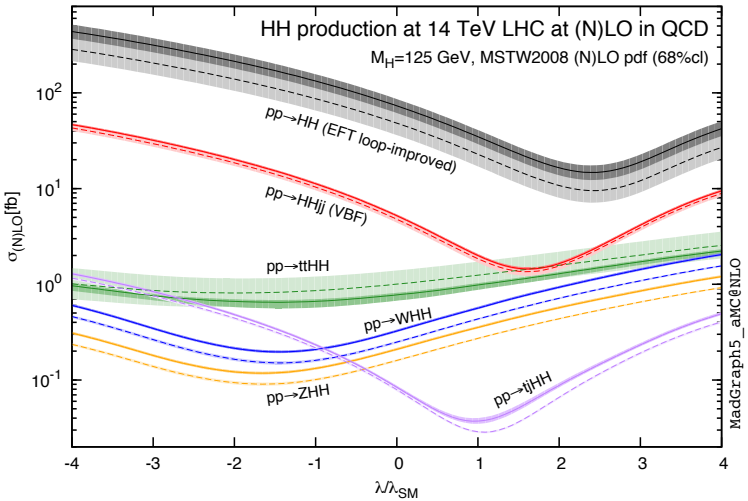
- the VBF production mode is subdominant, but it has a very clean signature

- the CMS L1 trigger system allows complex correlations between objects to be computed
  - many open possibilities: triggers can be analysis-targeted

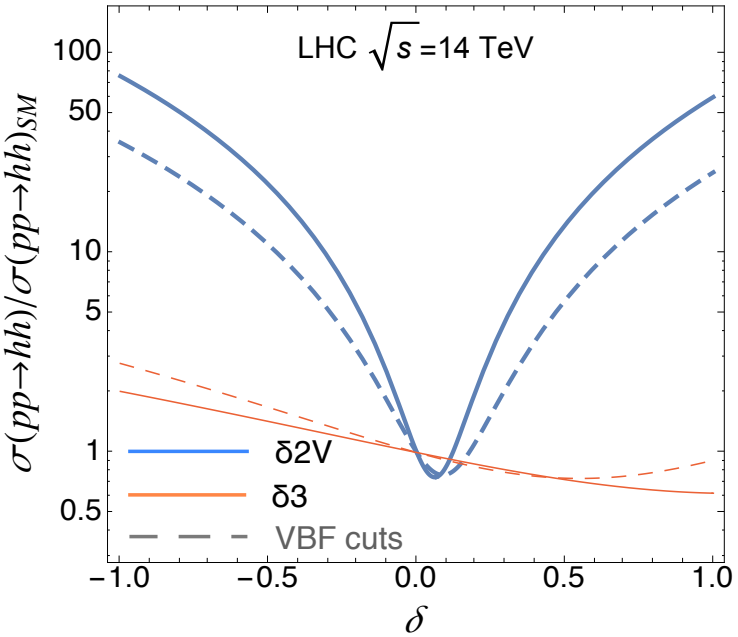
- the VBF signature can be exploited starting from trigger level
  - this is the first trigger targeting the production mode
  - by using it as a complement of the classic triggers, the coverage of the phase-space is expanded
  - it brings a large event yield gain ($\sim$58%) for VBF H $\rightarrow \tau\tau$ signal

Backup

Sensitivity to anomalous couplings



- different sensitivity to λ_3 for different production modes
- on the other hand, it is weak even for large variations



(arXiv:1401.7340)

- **high sensitivity on λ_{2V}**: σ/σ_{SM} up to 50 for $|\delta_{2V}| \sim 1$
  - $\delta = \lambda/\lambda_{SM} - 1$