

# Constraints on the Higgs boson width from *off-shell* production and decay to Z-boson pairs

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# Motivation

**Higgs boson discovery @  $M=125.6$  GeV,  $J^{PC}=0^{++}$ ,  $\Gamma_{SM}=4.15$  MeV**

Direct measurement

At the resonance peak



Limited by experimental  
resolution of the calorimeters  
( $\sim 1$  GeV)

Caola and Melnikov approach

Use ZZ events away from the  
resonance peak



$\sim 15\%$  of  $\sigma_{H \rightarrow 4l}$  comes  
from the off peak region

# Problem setting

Total cross section:  $\frac{d\sigma}{dm_{ZZ}^2} \propto \frac{g_{ggH}^2 g_{HZZ}^2}{(m_{ZZ}^2 - m_H^2)^2 + m_H^2 \Gamma_H^2}$

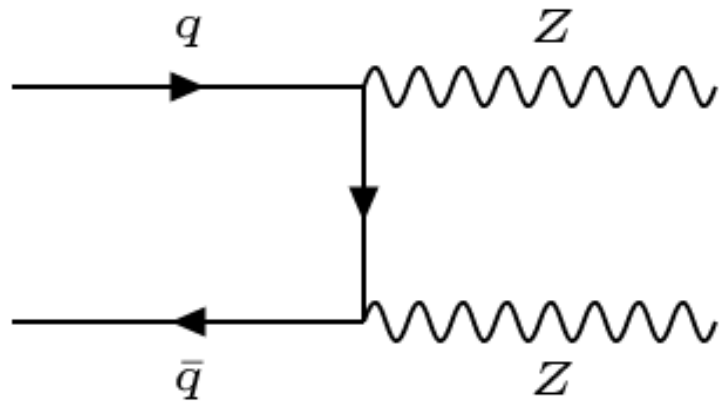
$$\sigma_{on-shell} \propto \frac{g_{ggH}^2 g_{HZZ}^2}{m_H \Gamma_H}$$

$$\sigma_{off-shell} \propto \frac{g_{ggH}^2 g_{HZZ}^2}{(2m_Z)^2}$$

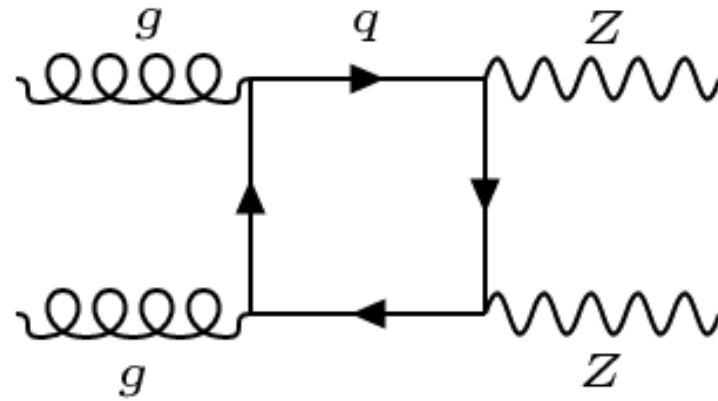
$$g_{ggH}^2 g_{HZZ}^2 \rightarrow \epsilon g_{ggH}^2 g_{HZZ}^2$$
$$\Gamma_H \rightarrow \epsilon \Gamma_H$$

$$\sigma_{off-shell} \propto \epsilon$$

# Main contributions

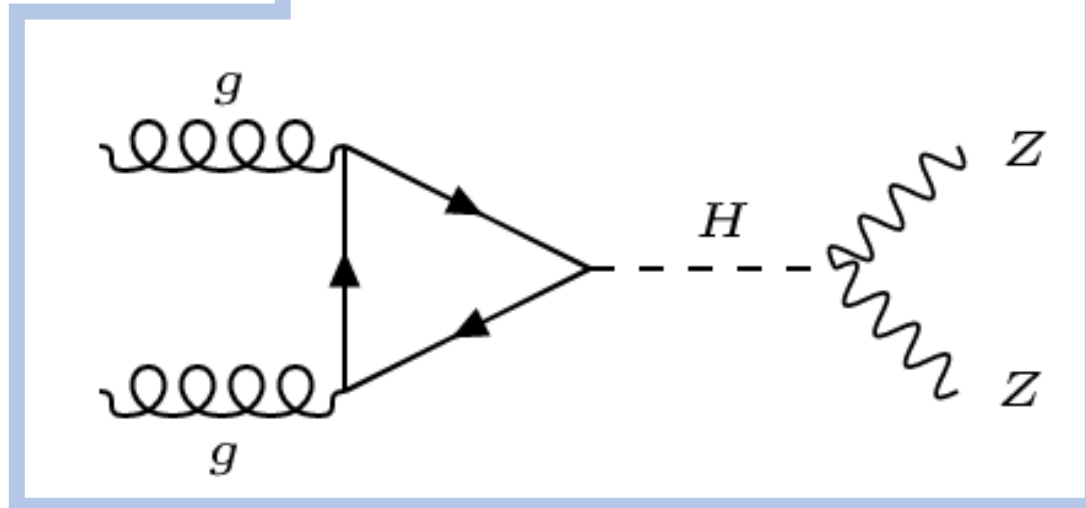


Dominant



Interference

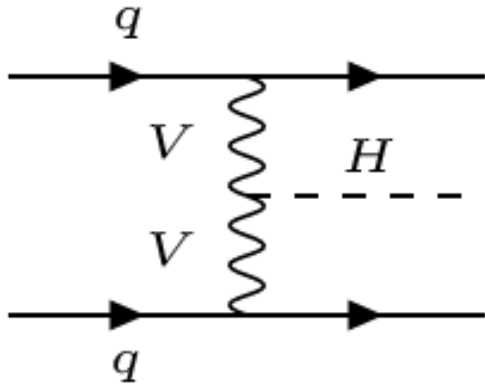
Background



Signal

# Other production modes

VBF (7%)



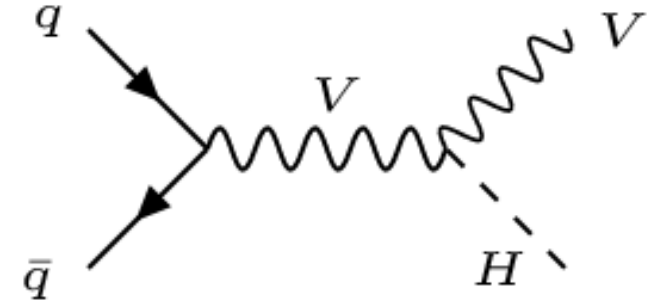
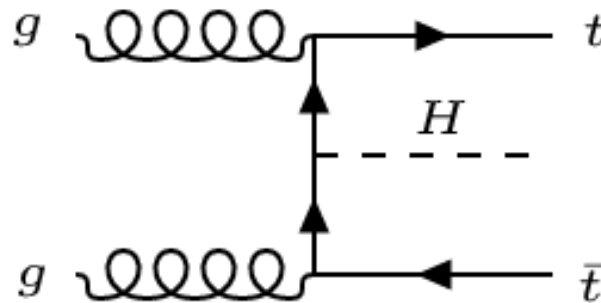
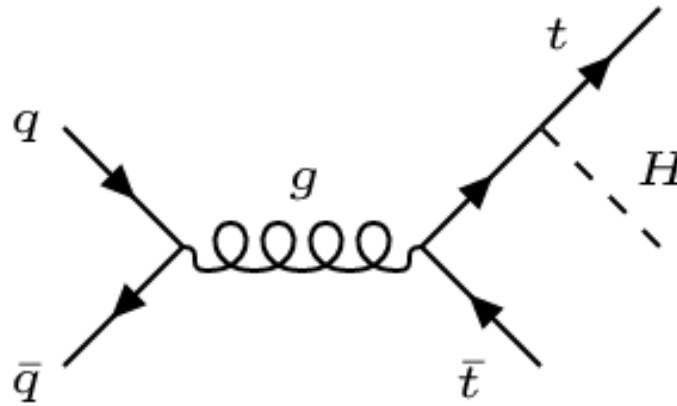
Constrained



Discriminant

$D_{jet}$

$ttH + VH$  (5%)



Supressed at high mass



Neglected in the off-shell analysis

# Detection channels

$$H \rightarrow ZZ \rightarrow 4l$$

$$L = 5.1 \text{ fb}^{-1}, \sqrt{s} = 7 \text{ TeV}$$

$$L = 19.7 \text{ fb}^{-1}, \sqrt{s} = 8 \text{ TeV}$$

**On-shell:**

$$105.6 < m_{4l} < 140.6 \text{ GeV}$$

**Off-shell:**  $m_{4l} > 220 \text{ GeV}$

$$H \rightarrow ZZ \rightarrow 2l2\nu$$

$$L = 19.7 \text{ fb}^{-1}, \sqrt{s} = 8 \text{ TeV}$$

Only **off-shell** analysis:

$$m_T > 180 \text{ GeV}$$

# 4l channel - signature

- Four well-identified and isolated leptons
- Originating from the same vertex (to suppress backgrounds)
- $40 < m_{Z_1} < 120 \text{ GeV}, 12 < m_{Z_2} < 120 \text{ GeV}$
- $p_{T,l} > 20 \text{ GeV}, p_{T,l} > 10 \text{ GeV}$
- $m_{l+l-} > 4 \text{ GeV}, m_{4l} > 100 \text{ GeV}$

# 4l channel - analysis

Matrix Element Likelihood Analysis

$$m_{Z_1}, m_{Z_2}, \vec{\Omega}$$

Separate **gluon-gluon** and **quark-initiated** processes in the off-shell region

$$D_{gg} = \frac{P_{tot}^{gg}}{P_{tot}^{gg} + P_{bkg}^{q\bar{q}}} = \left[ 1 + \frac{P_{bkg}^{q\bar{q}}}{a P_{sig}^{gg} + \sqrt{a} P_{int}^{gg} + P_{bkg}^{gg}} \right]^{-1} > 0.65$$

Four leptons invariant mass:  $m_{4l}^2$



# 4l channel

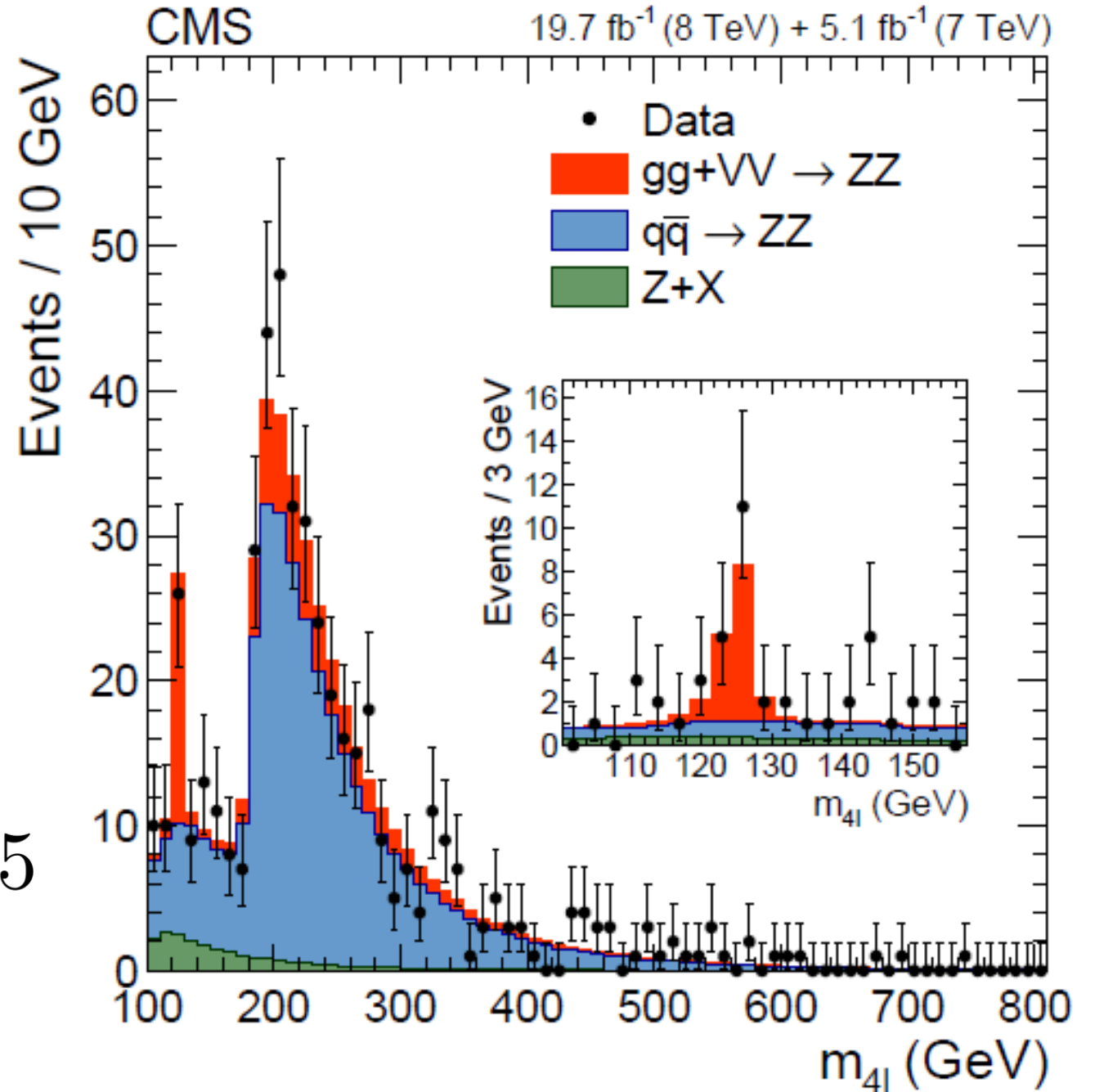
Observed

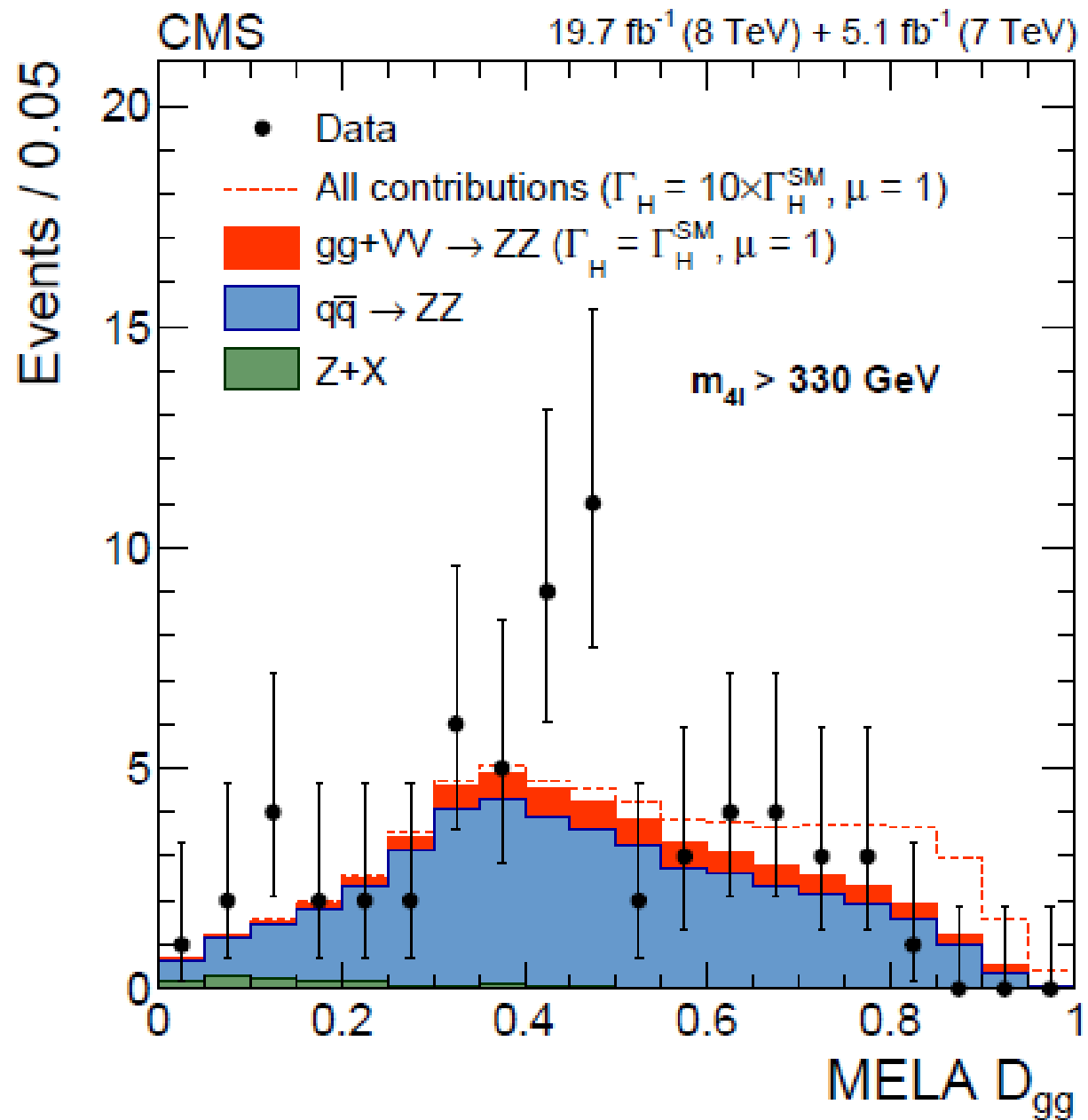
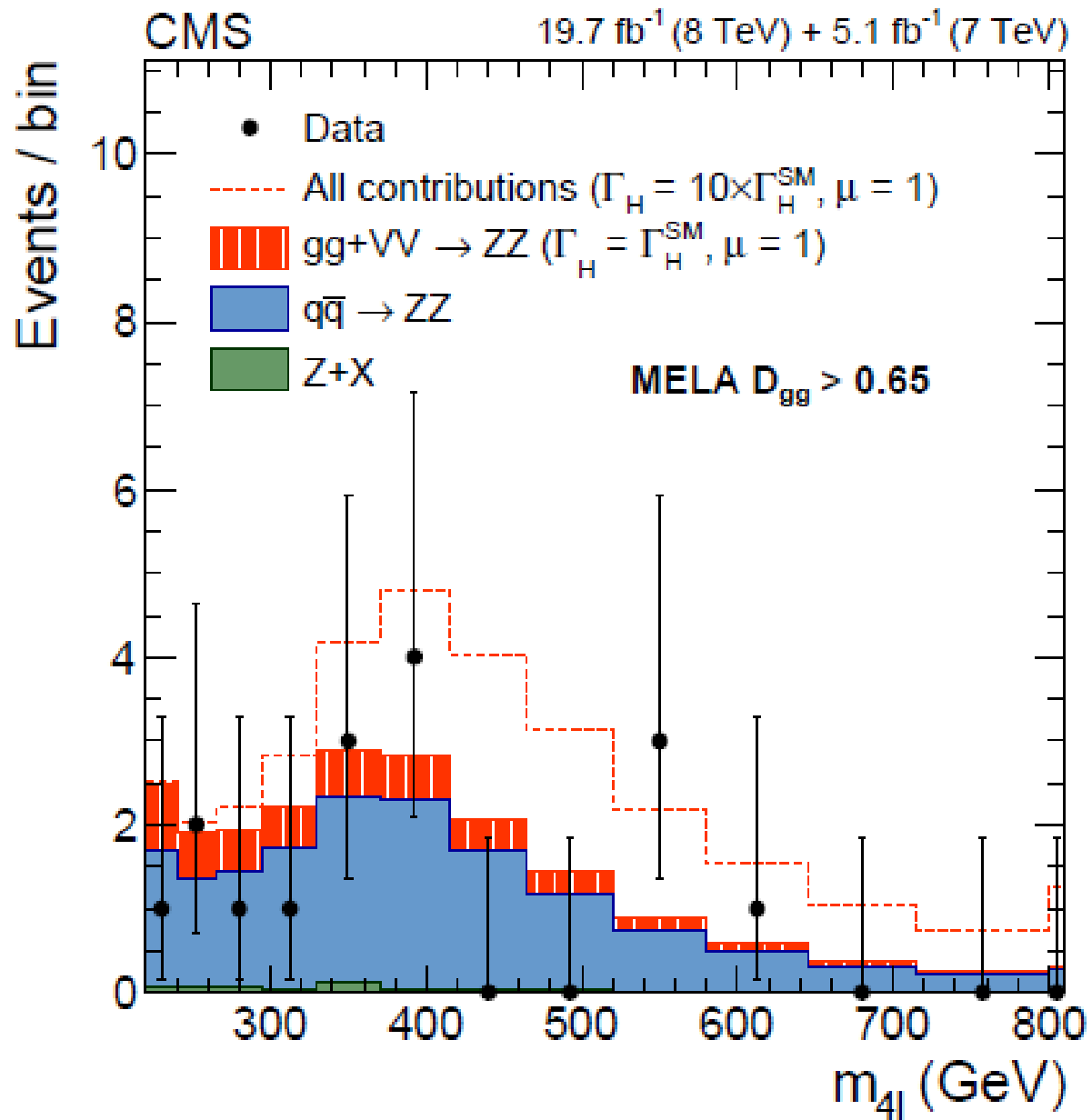
223 events

Expected

$217.6 \pm 9.5$  events  
from SM processes

$$D_{bkg}^{kin} = \frac{P_{0+}^{kin}}{P_{0+}^{kin} + P_{bkg}^{kin}} > 0.5$$





# 2l2v channel - signature

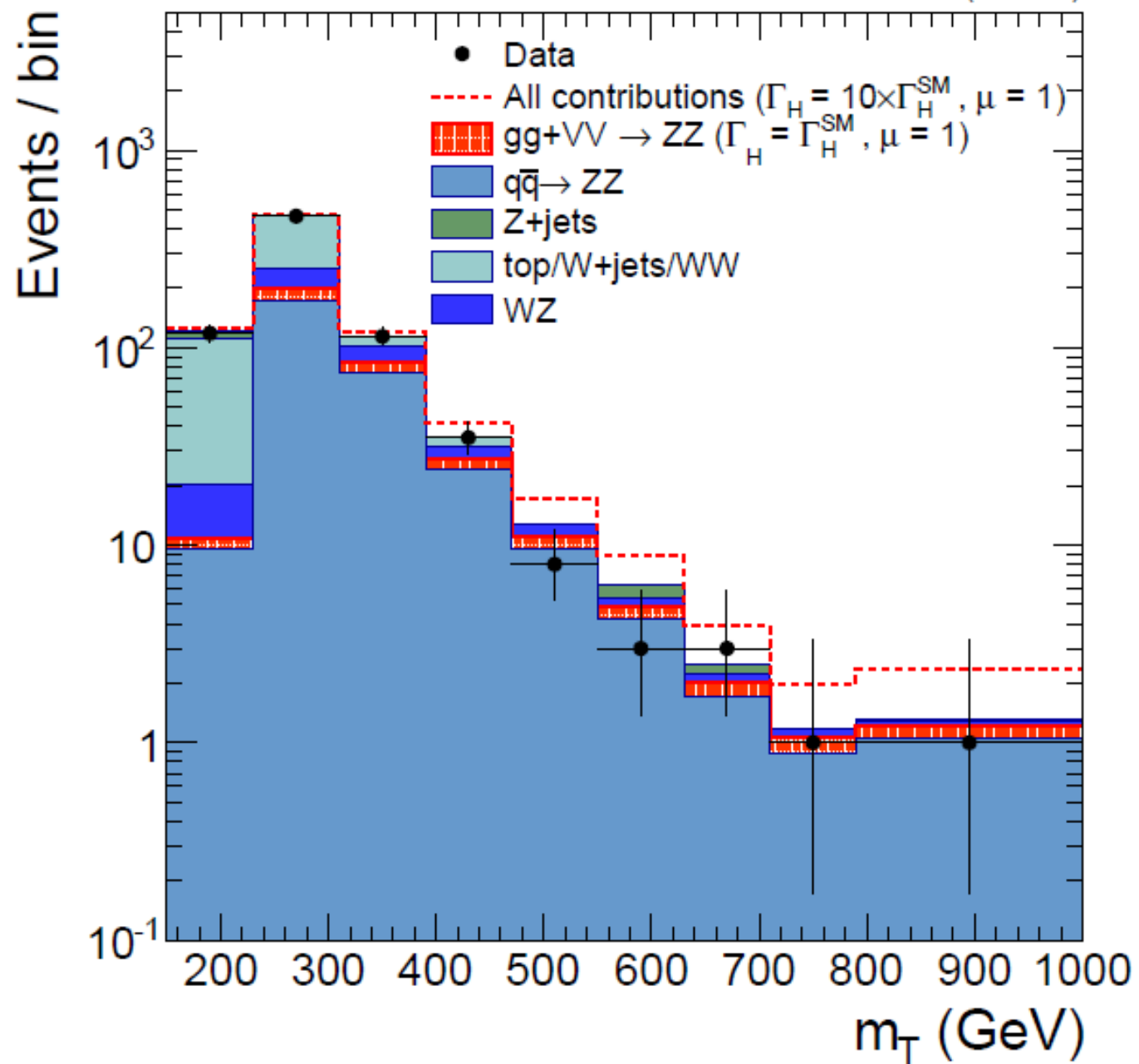
- Pair of well-defined, isolated leptons of the same flavour ( $e^+e^-$ ,  $\mu^+\mu^-$ )
- Large missing transverse energy
- $p_T > 20 \text{ GeV}$ ,  $m \in M_Z \pm 30 \text{ GeV}$
- $p_{T,2l} > 30 \text{ GeV}$
- Jets:  $p_T > 55 \text{ GeV}$ ,  $|\eta| < 5$

# 2l2v channel – analysis

Transverse mass:  $m_T^2$

$$m_T^2 = \left[ \sqrt{p_{T,2l}^2 + m_{2l}^2} + \sqrt{E_{T,miss}^2 + m_{2l}^2} \right]^2 - \left[ p_{T,2l}^{\vec{}} + E_{T,miss}^{\vec{}} \right]^2$$

CMS

19.7 fb<sup>-1</sup> (8 TeV)

# Fit the data

- Simultaneous unbinned maximum likelihood fit of signal+background in both channels

4l channel

on-shell  $\vec{x} = (m_{4l}, D_{bkg}^{kin}, p_{T,4l}$  or  $D_{jet})$

off-shell  $\vec{x} = (m_{4l}, D_{gg})$

2l2v channel

$$\vec{x} = m_T$$

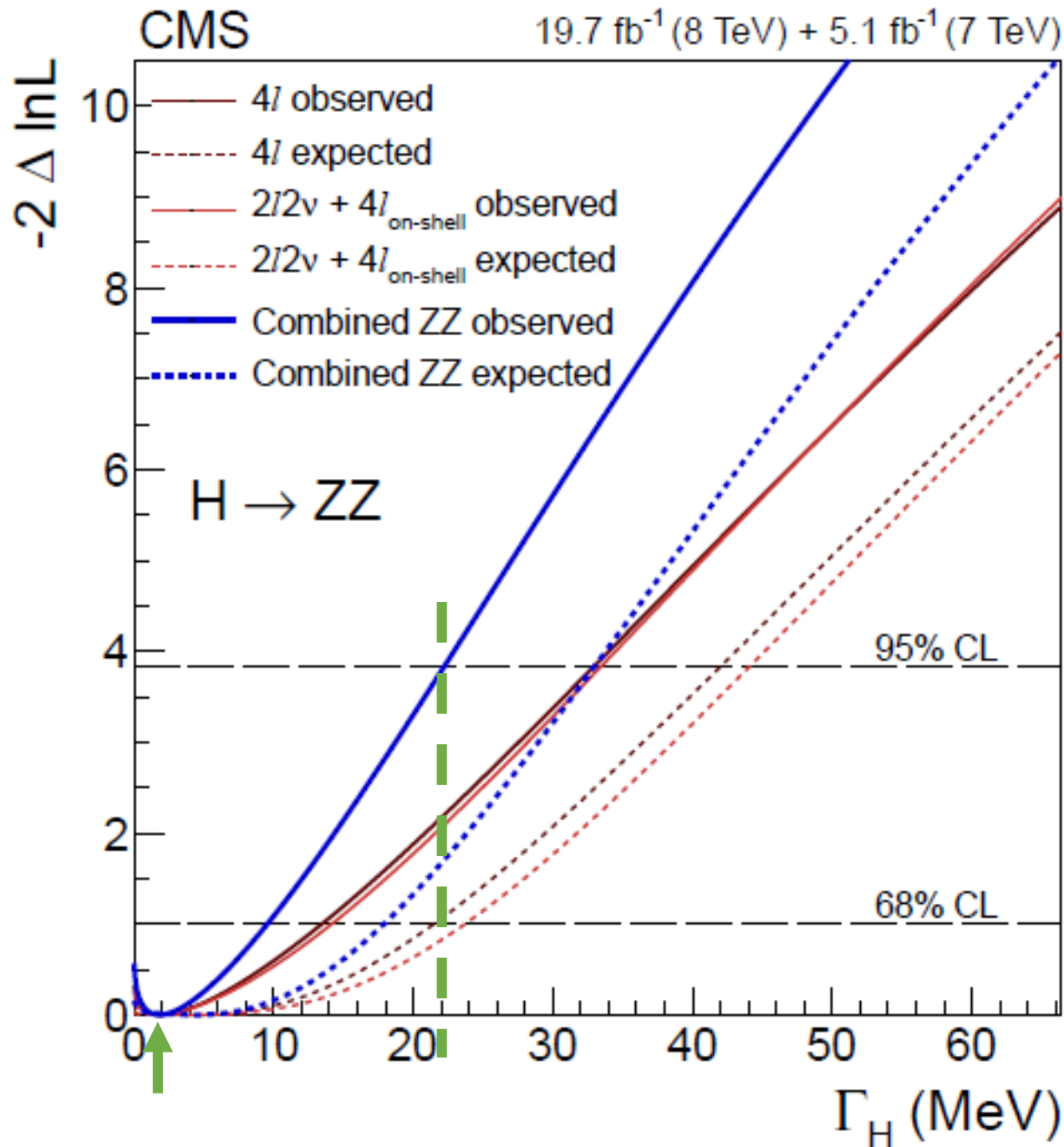
Separate **VBF** from  
**gluon fusion**  
production

$$P_{tot}^{off-shell}(\vec{x}) =$$

$$\begin{aligned}
& \left[ \mu_{ggH} \frac{\Gamma_H}{\Gamma_0} P_{sig}^{gg}(\vec{x}) + \sqrt{\mu_{ggH} \frac{\Gamma_H}{\Gamma_0}} P_{int}^{gg}(\vec{x}) + P_{bkg}^{gg}(\vec{x}) \right] \\
& + \left[ \mu_{VBF} \frac{\Gamma_H}{\Gamma_0} P_{sig}^{VBF}(\vec{x}) + \sqrt{\mu_{VBF} \frac{\Gamma_H}{\Gamma_0}} P_{int}^{VBF}(\vec{x}) + P_{bkg}^{VBF}(\vec{x}) \right] \\
& + P_{bkg}^{q\bar{q}}(\vec{x}) + \dots
\end{aligned}$$

$$P_{tot}^{on-shell}(\vec{x}) =$$

$$\begin{aligned}
& \mu_{ggH} \left[ P_{sig}^{gg}(\vec{x}) + P_{sig}^{t\bar{t}H}(\vec{x}) \right] + \mu_{VBF} \left[ P_{sig}^{VBF}(\vec{x}) + P_{sig}^{VH}(\vec{x}) \right] \\
& + P_{bkg}^{q\bar{q}}(\vec{x}) + P_{bkg}^{gg}(\vec{x}) + \dots
\end{aligned}$$



**Parâmetros livres:**

$$\mu_{ggH} \sim 0.8, \mu_{VBF} \sim 1.7$$

$$\Gamma_H$$

$$\Gamma_H < 22 \text{ MeV} @ 95\% \text{ CL}$$

$$\Gamma_H = 1.8^{+7.7}_{-1.8} \text{ MeV}$$



# Obrigada

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