Photon identification and properties of the Higgs boson in the VBF production mode using the $H \rightarrow \gamma\gamma$ decay channel

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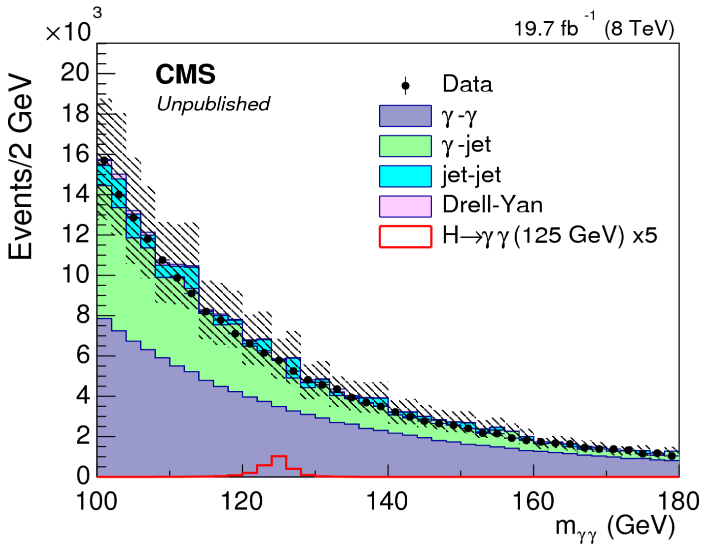
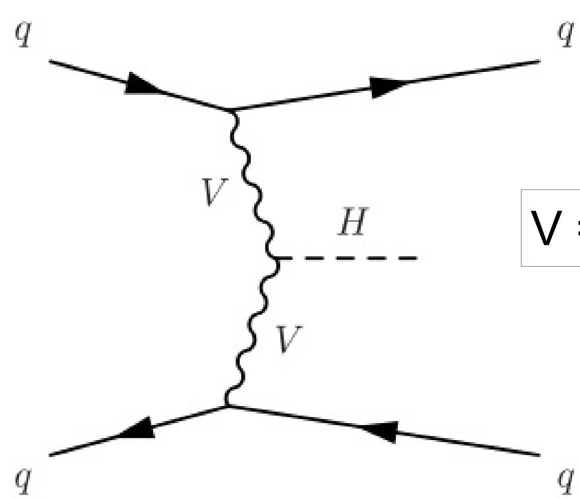
Outline

- The Higgs boson and its decay in two photons
- Photon identification studies at 13 TeV
- Analysis on HVV couplings in VBF production at 8 TeV





V = Z/W bosons

VBF = Higgs production by Vector Boson Fusion

The Higgs boson and its decay in two photons

The Higgs boson

- In 1970s: unification between weak and electromagnetic interactions → electroweak interaction

- Unified theory → massless interaction-mediator bosons. Experimentally: W and Z bosons massive (short range interaction)

  - **W/Z mass = 80/91 GeV,** m_{proton} = 1 GeV

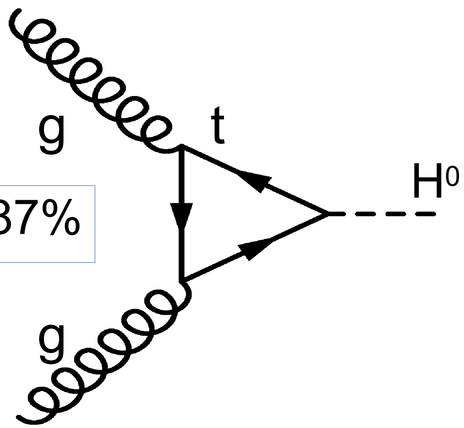
- Problem solved by the Higgs mechanism:

  - Spontaneous symmetry breaking of electroweak interaction → W and Z mass
  - There must exist a new spin 0 particle, called Higgs boson, footprint of the mechanism
  - Higgs boson discovered at the LHC, **mass = 125 GeV**
  - Next: study properties of the new particle

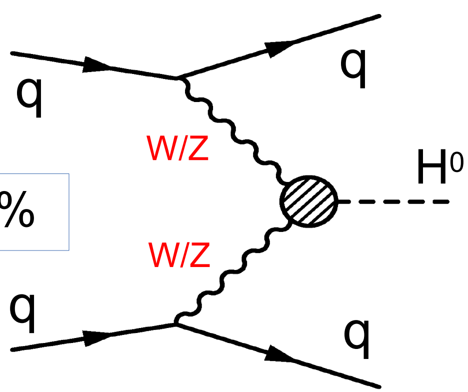
The Higgs boson: production and decays

SM: particles mass proportional to their coupling strength to the Higgs boson

ggH – 87%



VBF – 7%



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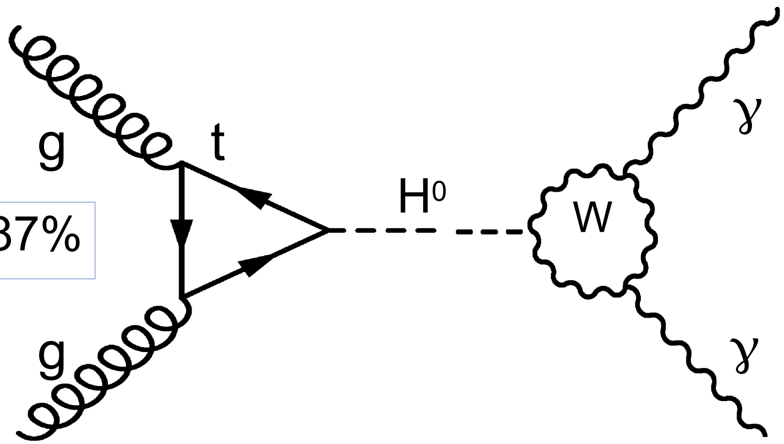
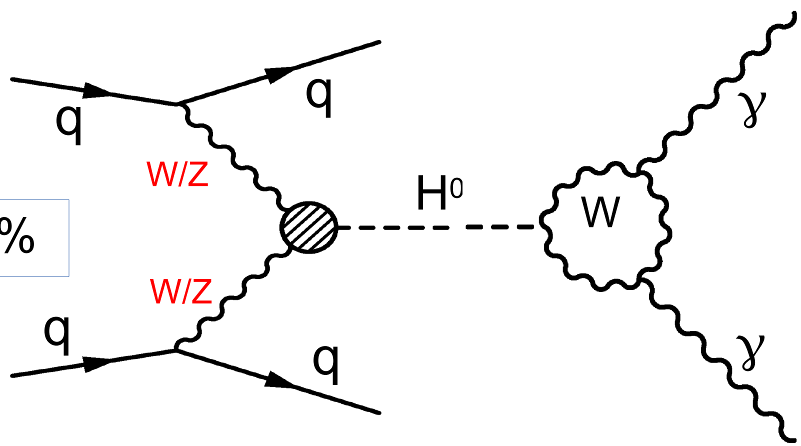


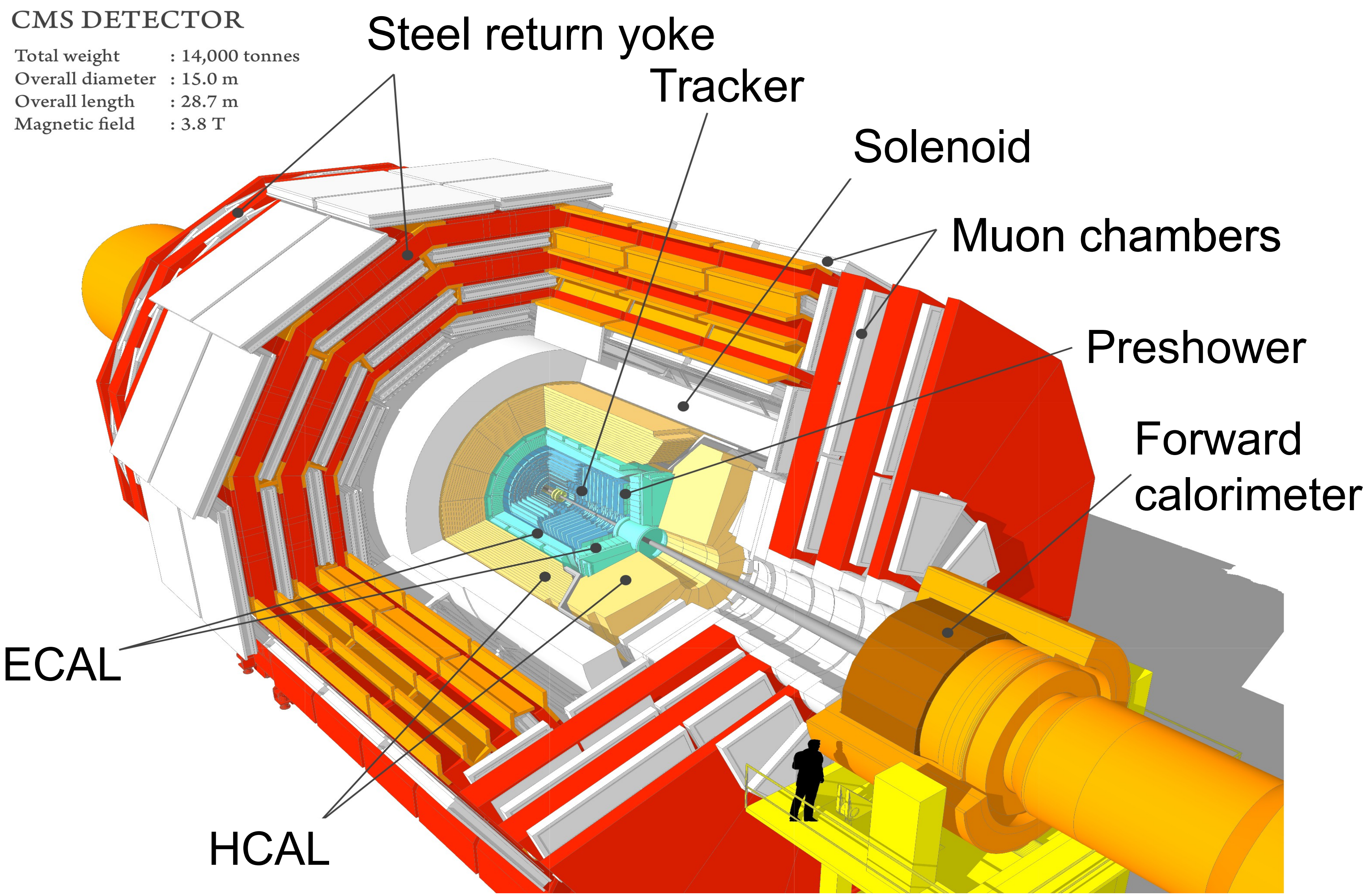
VBF – 7%



Decay	BR @125 GeV
bb	57%
WW	21%
ττ	6.4%
ZZ	2.6%
γγ	0.2%

Higgs decay in 2 photons: low branching ratio but clear experimental signature thanks to excellent diphoton mass resolution

The CMS detector and the electromagnetic calorimeter



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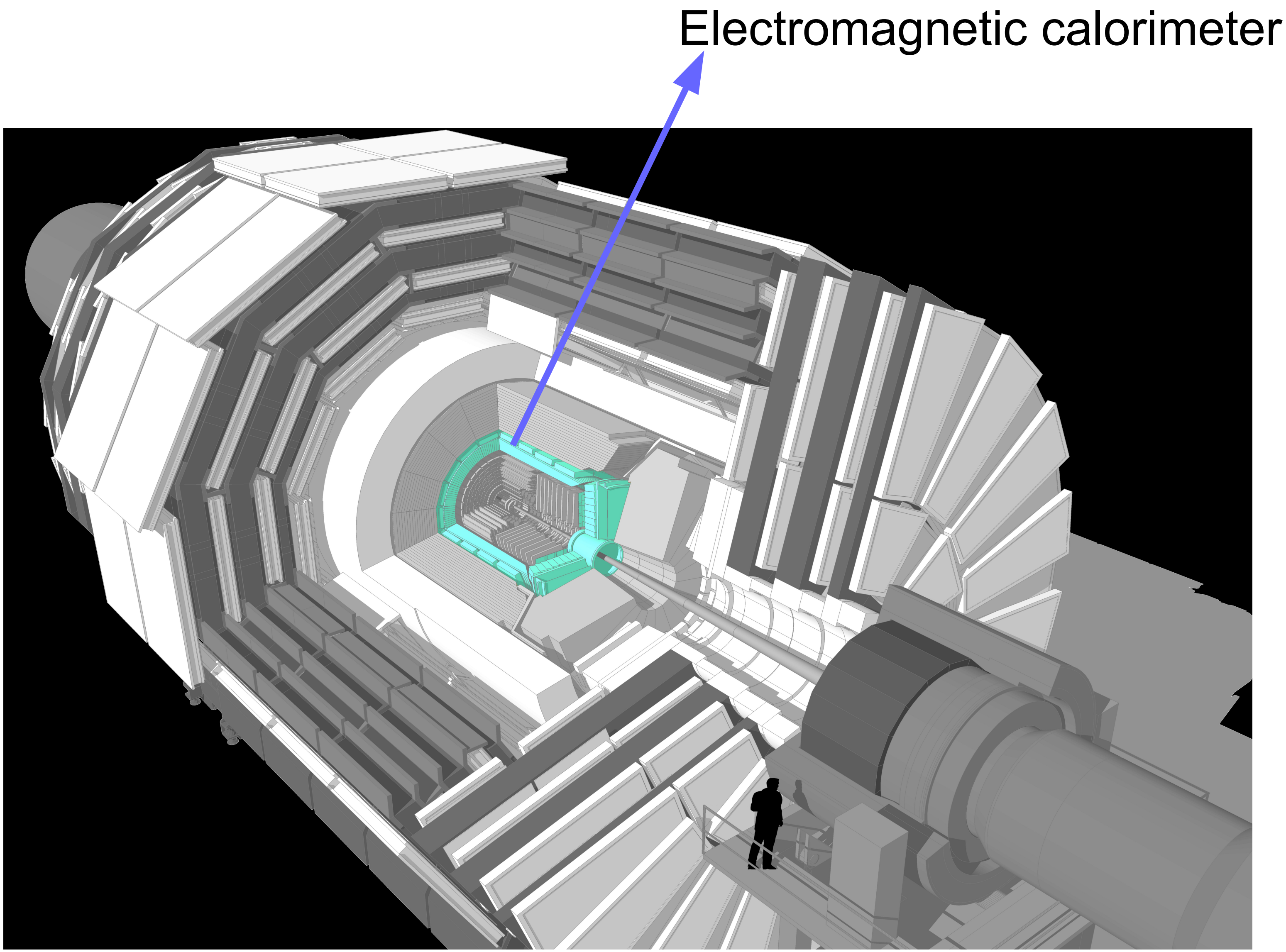

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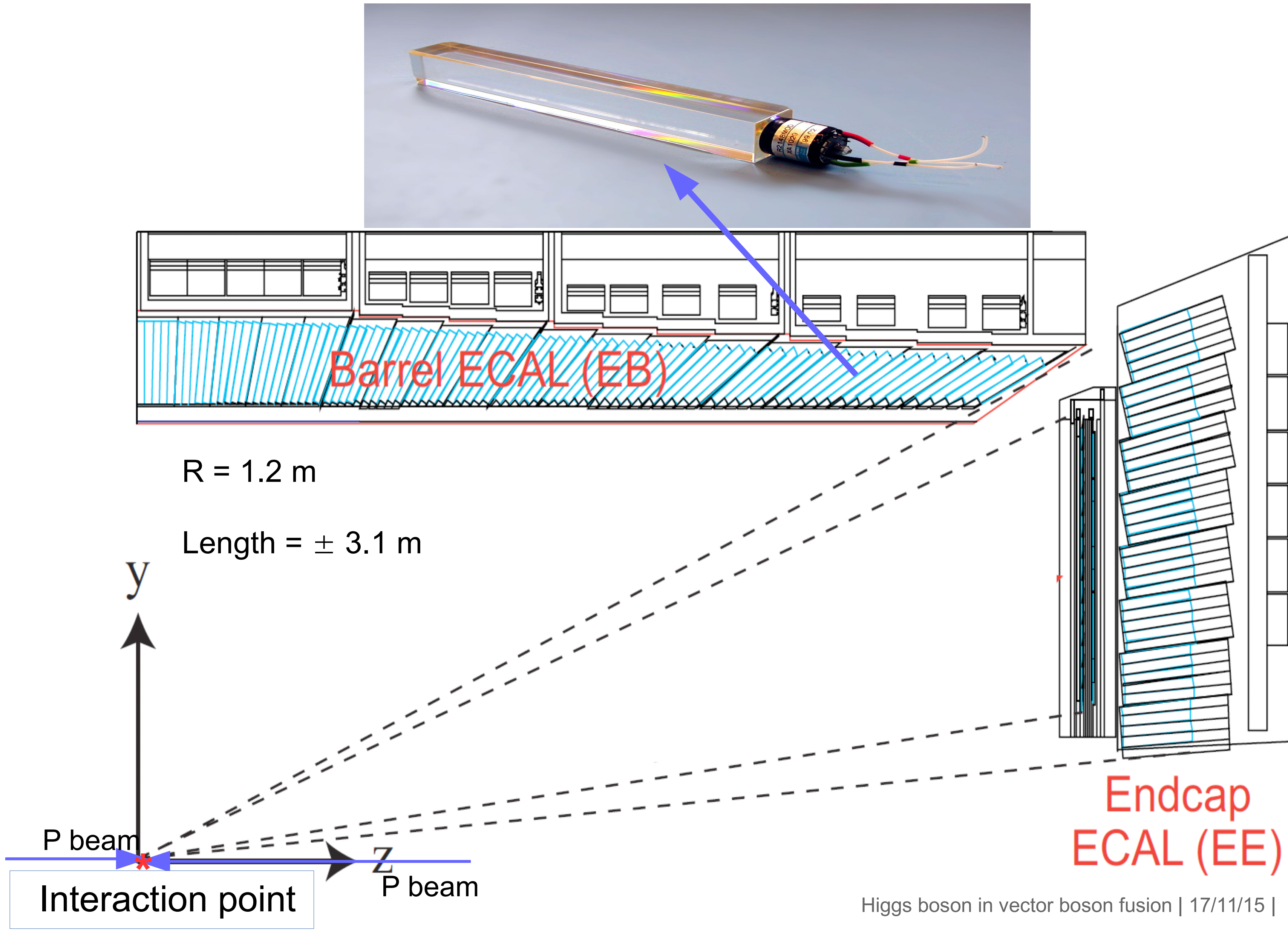
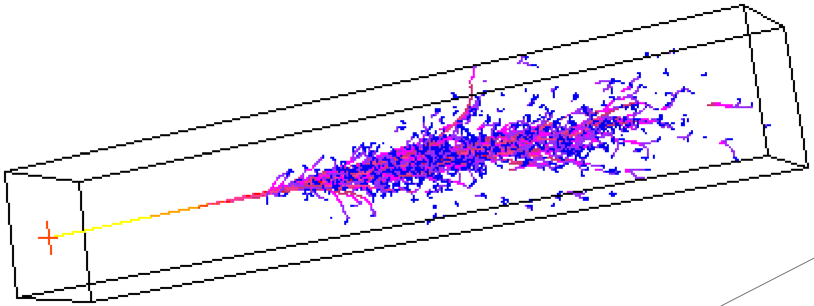
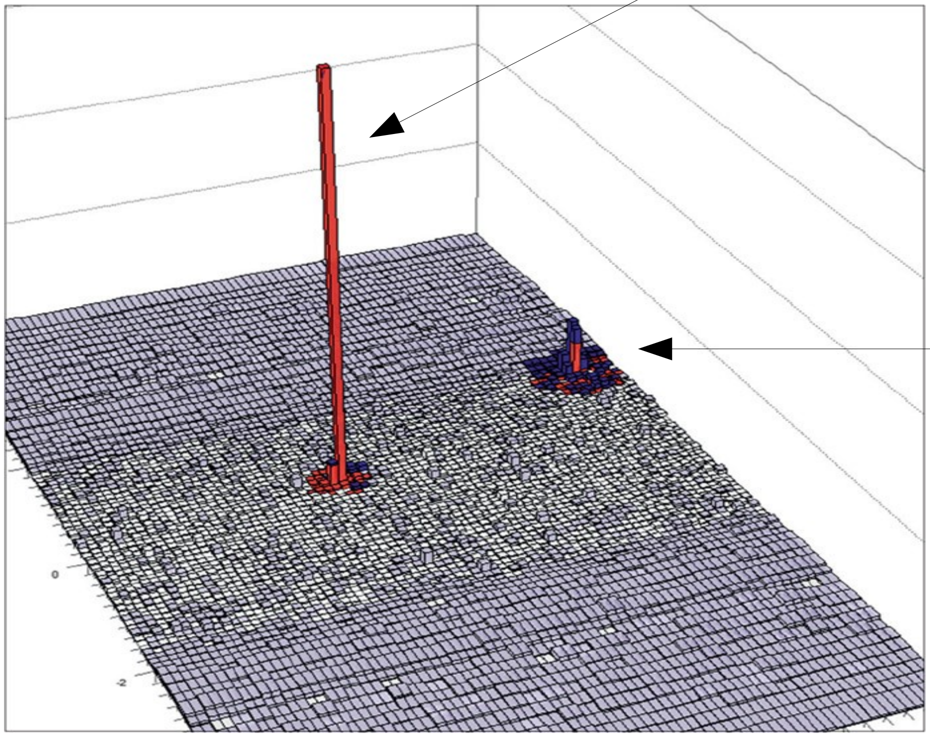


Electromagnetic shower





$\color{blue}{\text{prompt}}$ photon: directly emitted in the hard scatter vertex (as opposed to photons emitted in jets hadronization)

compact shower

$\color{red}{\text{fake}}$ photon: mostly jets (*e.g.* $\pi^0 \rightarrow \gamma\gamma$)

broader shower

Photon identification studies at 13 TeV

Photon identification principles

Photon identification: discriminate between prompt and fake photons :

- Prompt photons = signal (hard scatter vertex)
- Fake photons = background (jets)

How to do this?

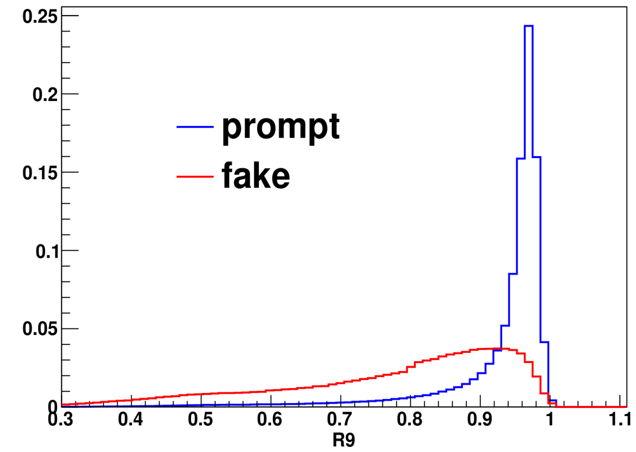
Using variables describing well the shower and energy deposits features:

- Electromagnetic Shower Shape Variables
- Isolation Variables

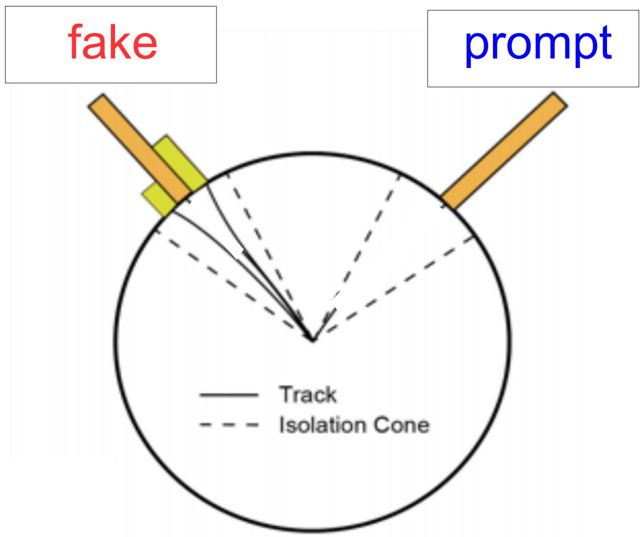
Photon identification variables

Some examples of interesting variables:

- **R9**: ratio of the energy in the 3x3 crystals matrix to the total energy of the shower



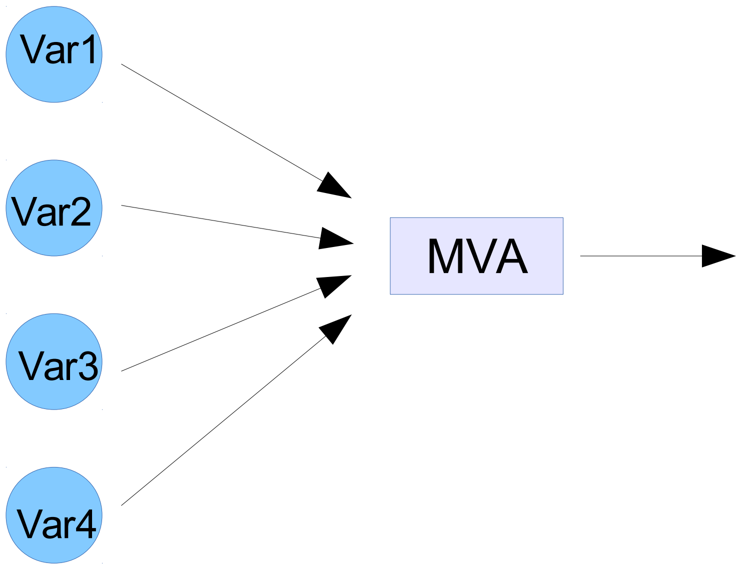
- **Isolation**: energy sum of all charged and neutral particles around the considered photon.
  Isolated photon = small value of this sum

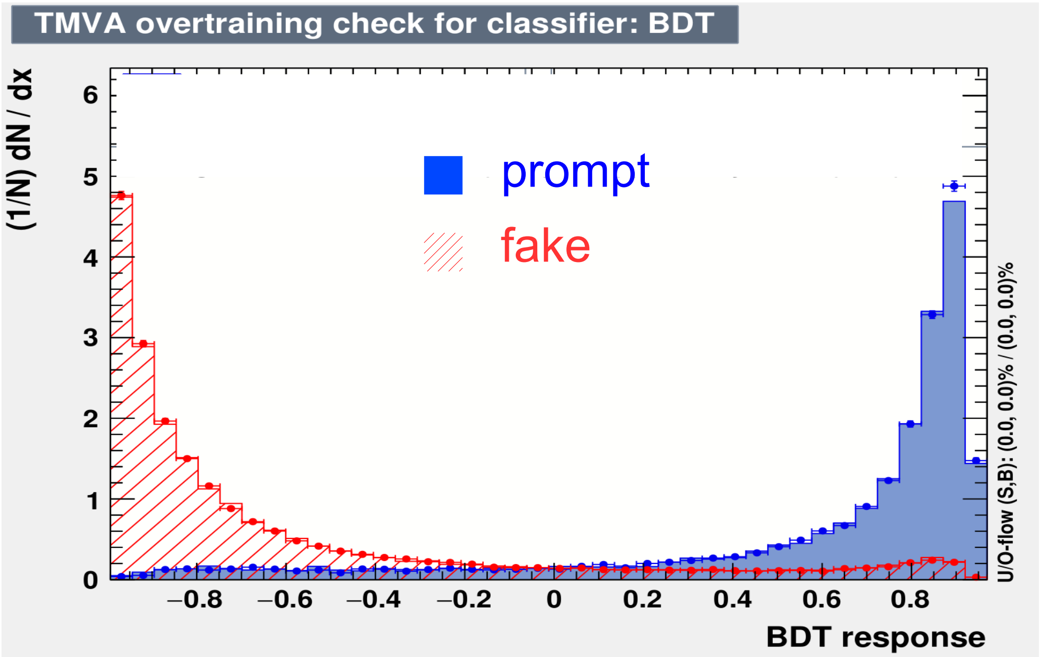


Photon identification Multi Variate Analysis (MVA)

All photon identification variables combined in a unique variable using MVA technique:

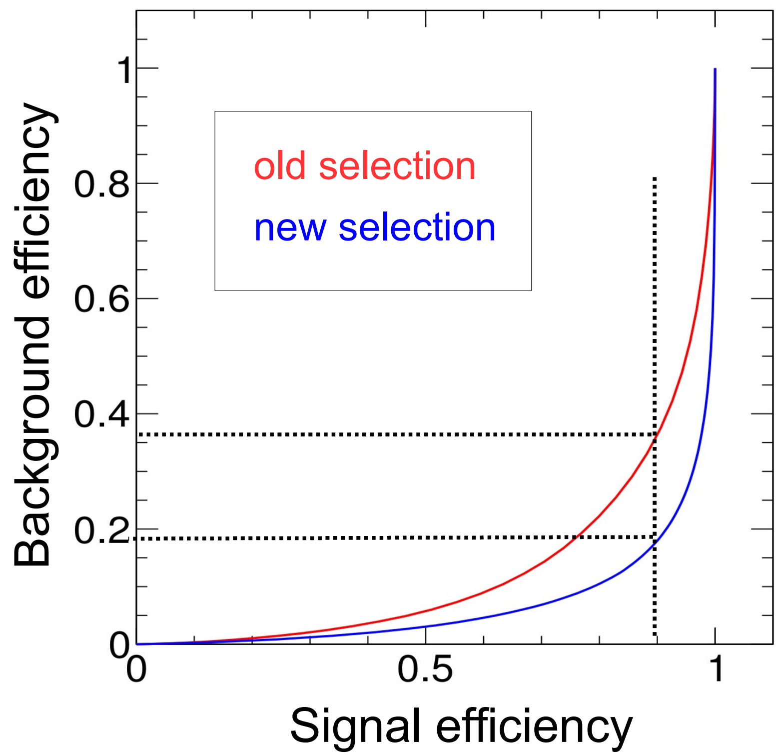
- MVA: util that allow to classify events belonging to different categories
- MVA trained on simulated samples of prompt and fake photons





Photon identification results

Need to optimize selection for 13 TeV analysis



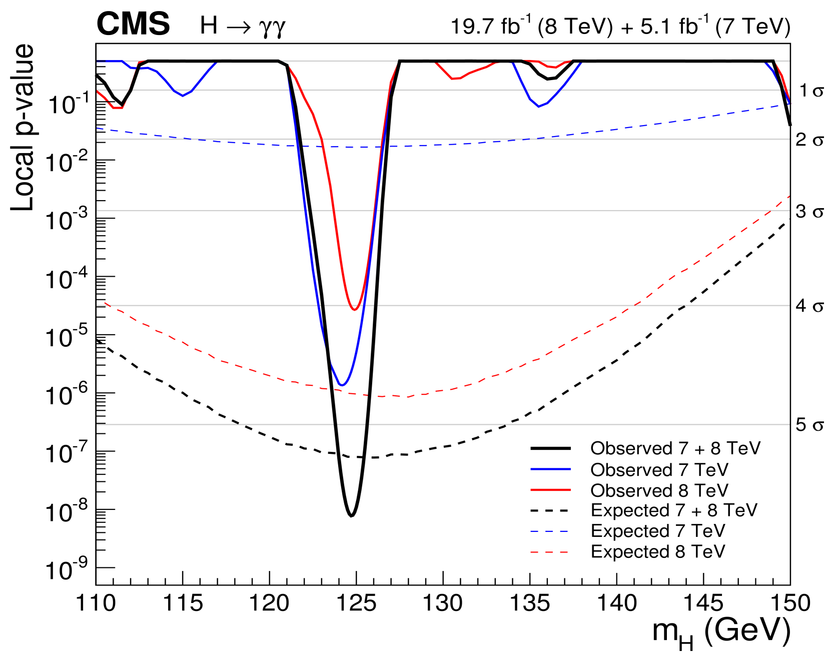
Old selection = 7/8 TeV analysis

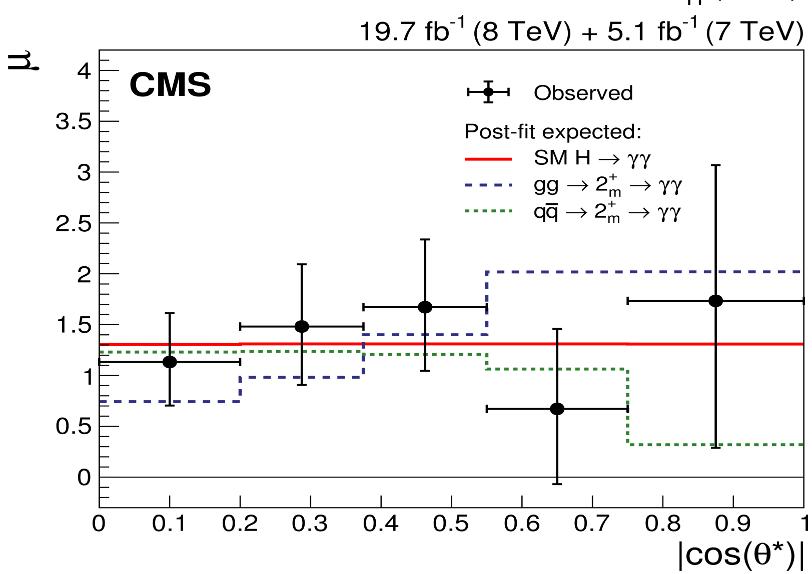
New selection = optimization for 13 TeV analysis

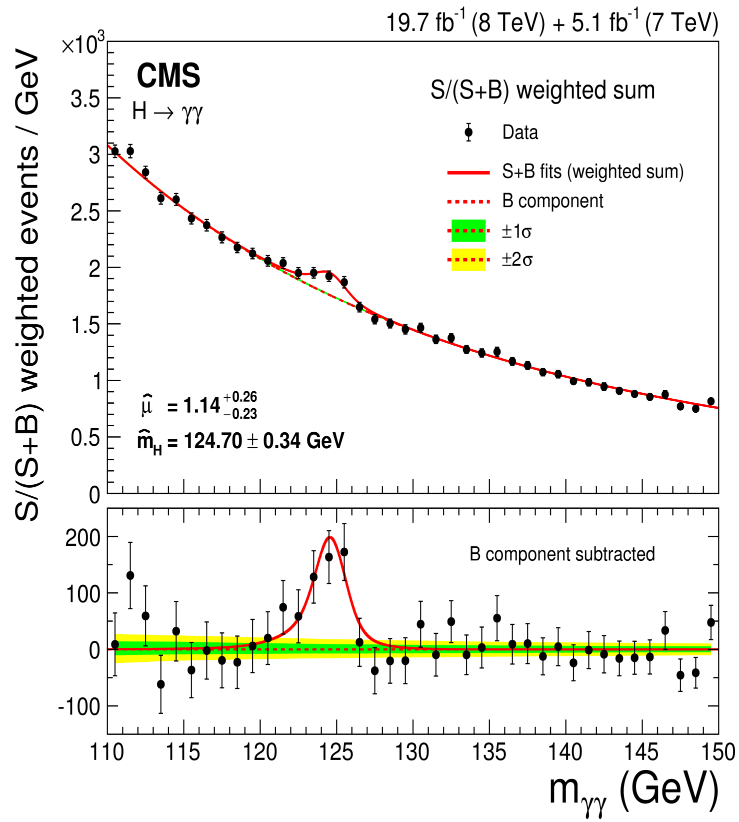
For a signal efficiency of ~90% the background efficiency is ~20%

Probing the HVV couplings in VBF production at 8 TeV

State of the art of the H→γγ channel





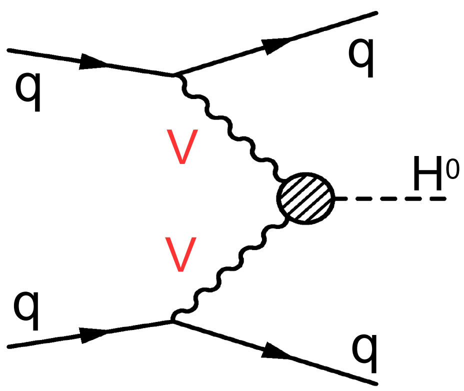


Spin studies already performed, and parity ?

Theory and couplings to probe

3 amplitudes contribute to VBF production:

$$\mathcal{A}(HVV) \sim a_1\, m_V^2\, \mathcal{A}_{\text{scalarSM}} + a_2\, \mathcal{A}_{\text{scalar anomalous}} + a_3\, \mathcal{A}_{\text{pseudo-scalar}}$$

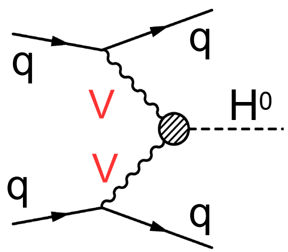


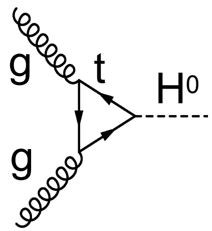
- a_i : all possible HVV couplings
  - **In SM: a_1= 1, a_2= a_3= 0**
- Want to measure the fraction of :
  - pseudo scalar production (related to a3)
  - anomualous scalar production (related to a2)
- For now concentrate on pseudo-scalar production

Physics processes and analysis strategy

Goal: constrain the pseudoscalar contribution

VBF scalar (0^+)	VBF pseudoscalar (0^-)	ggH	non-Higgs background

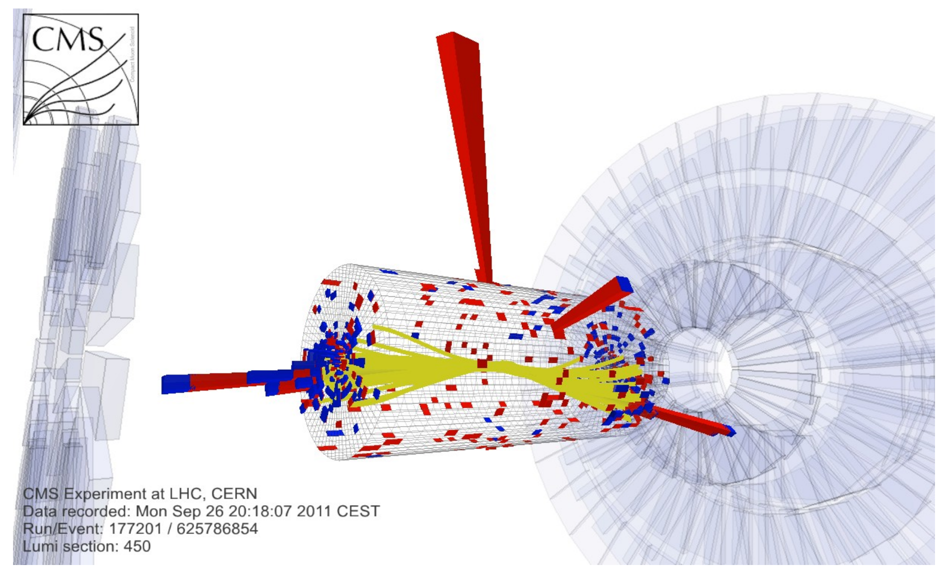




General Analysis Strategy:

- Apply VBF selection:

  require two isolated photons and two forward jets



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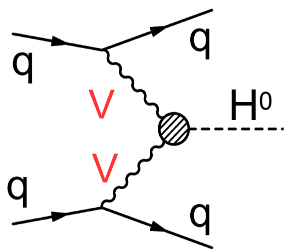

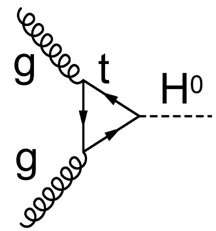

General Analysis Strategy:

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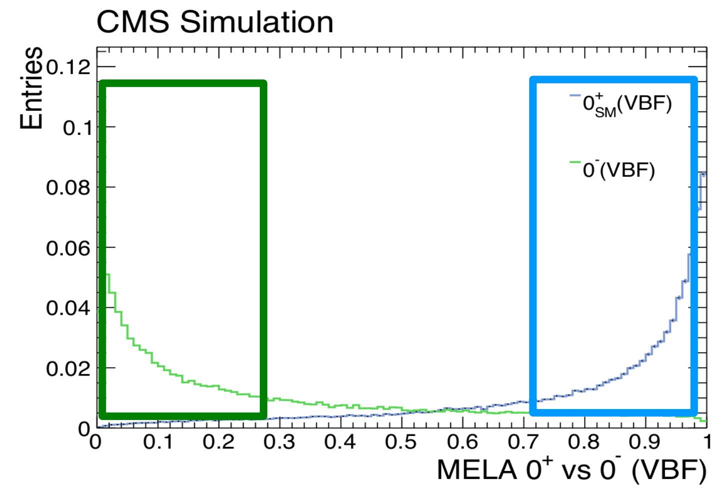
- Construct VBF vs ggH and VBF(0+) vs VBF(0-) discriminants to classify the different Higgs productions



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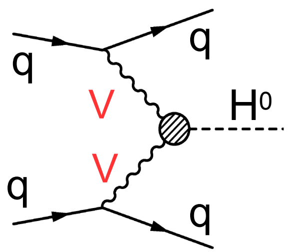
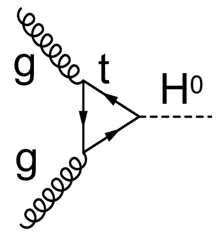




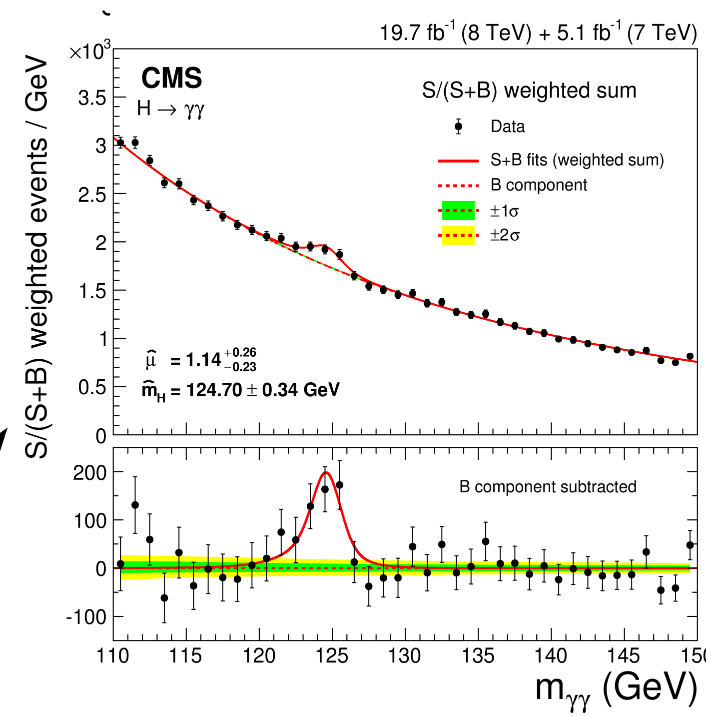
General Analysis Strategy:

- Apply VBF selection:

  require two isolated photons and two forward jets

- Construct VBF vs ggH and VBF(0+) vs VBF(0-) discriminants to disentangle the different Higgs productions

- Determine different regions of phase-space enriched with a certain process and extract Higgs signal yields from a fit to the diphoton mass



Classifying Higgs boson production processes

diphoton and jet kinematics

↓

MELA
(Matrix Element Likelihood Analysis)

$$P_i(\vec{x}) = \frac{1}{\sigma_i}\frac{d\sigma_i}{d\vec{x}}$$

theoretical differential cross section for the different processes i assuming a given event kinematics x

$$D_{VBF} = \frac{P(0^+|VBF)}{P(0^+|VBF) + P(0^+|ggH)}$$

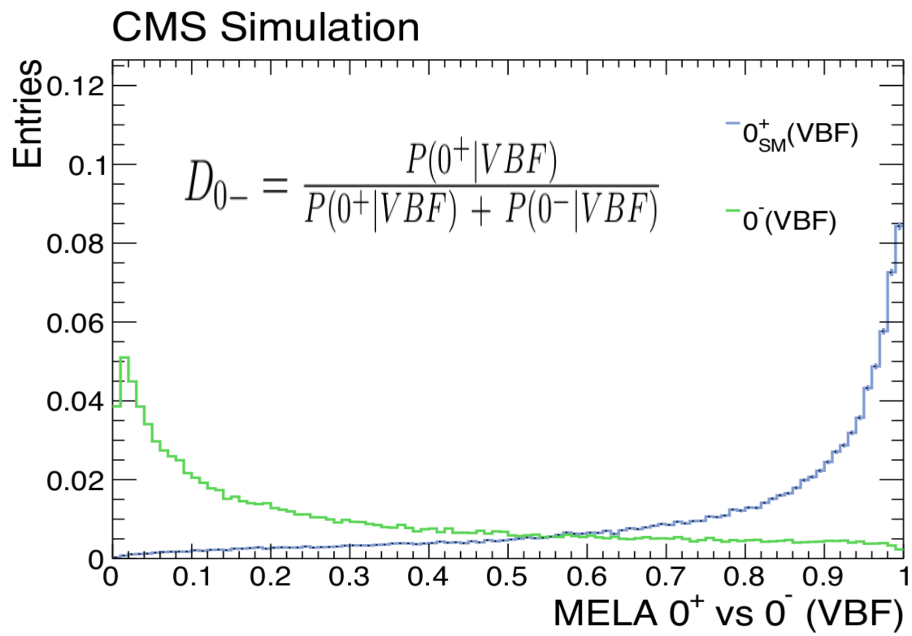
D_{VBF} = discriminate VBF vs ggH production

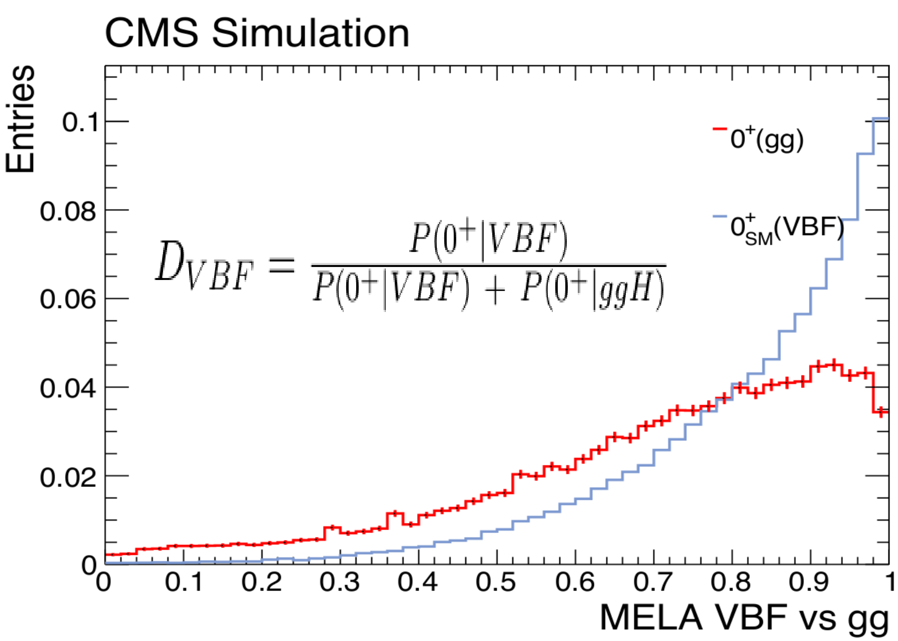
$$D_{0-} = \frac{P(0^+|VBF)}{P(0^+|VBF) + P(0^-|VBF)}$$

D_{0-} = discriminate VBF(0+) vs VBF(0-) production

MELA discriminants, 1D histograms

Very good VBF 0+/0- discrimination !



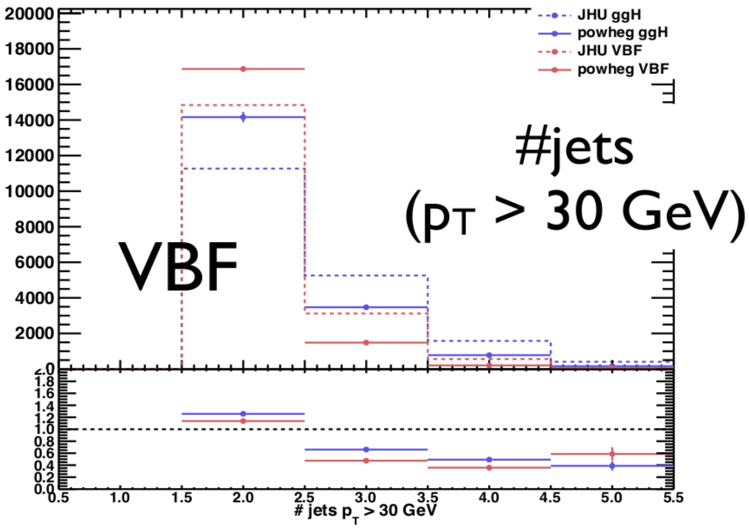


With VBF selection ggH events are VBF-like

- Before selection: 7% VBF – 87% ggH
- After selection: 60% VBF – 40% ggH

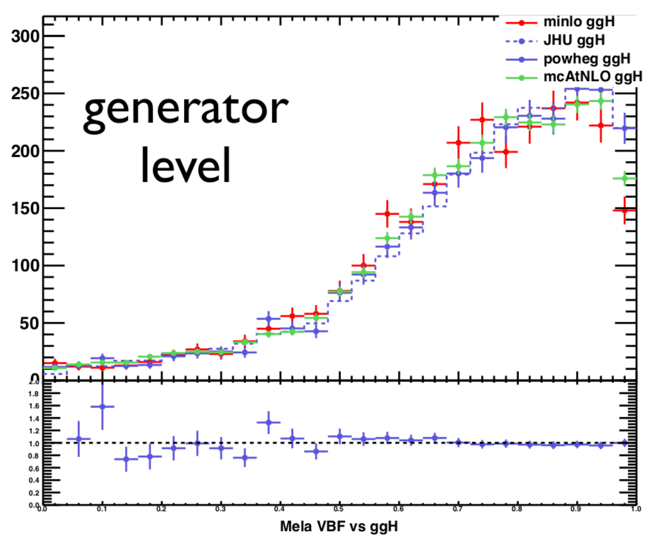
Studies on systematic uncertainties

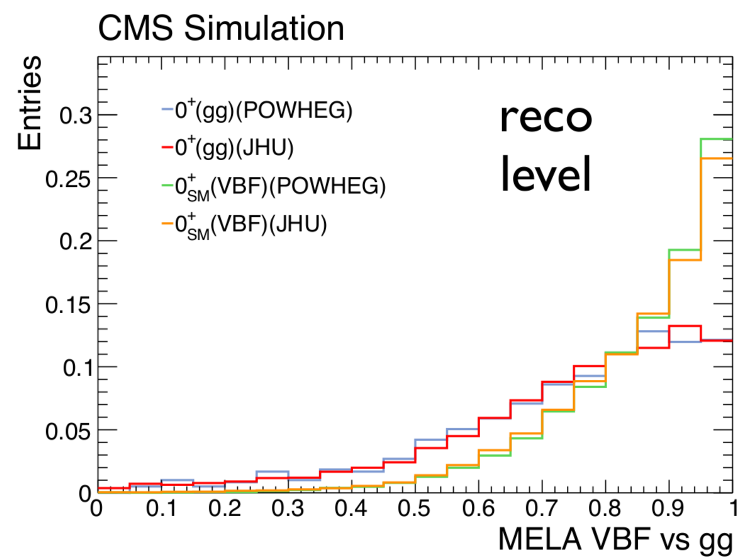
Some systematics studies on signal modeling are ongoing



jet multiplicity is higher in JHU samples

the VBF/ggH MELA discriminant does not
seem to be significantly affected

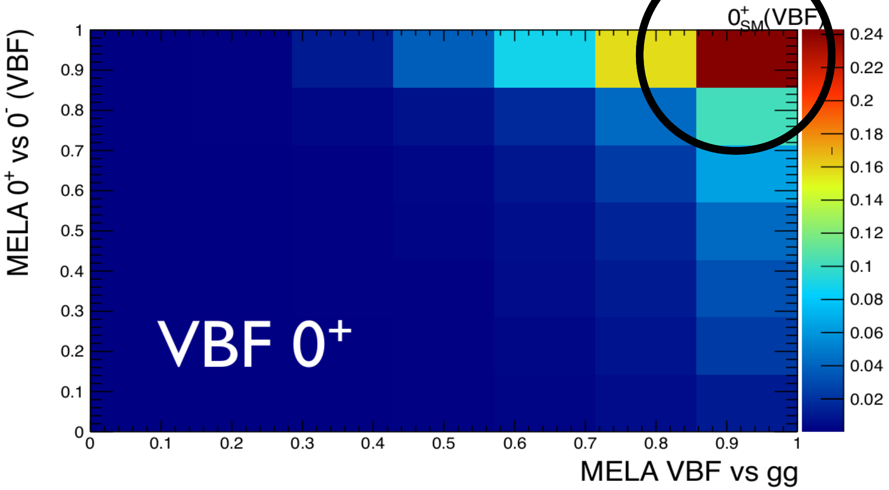


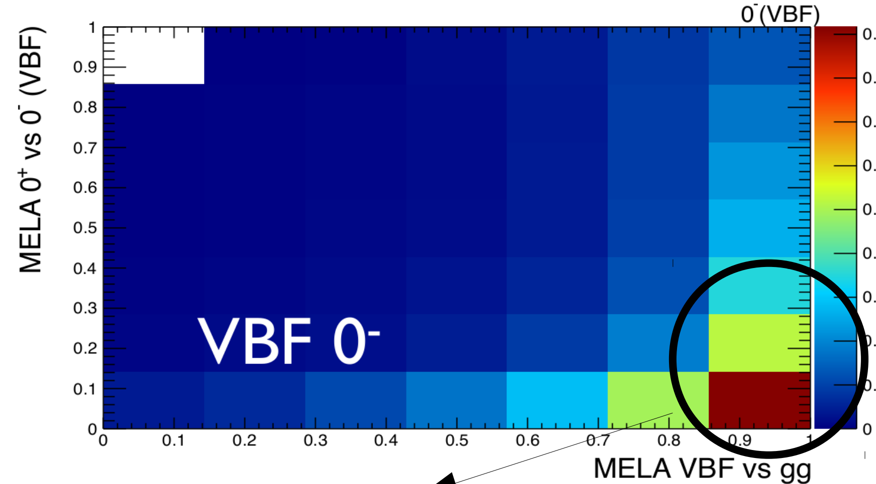


MELA discriminants, 2D maps

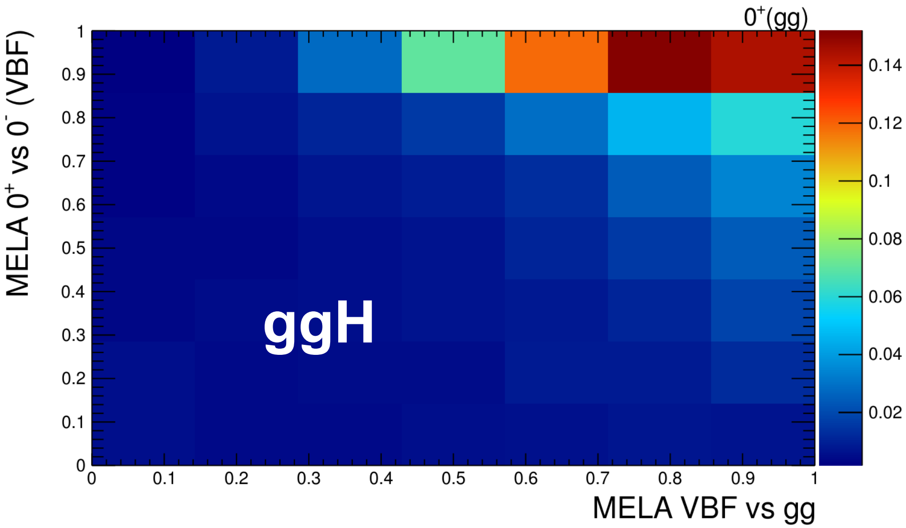
VBF 0+ region

normalised to 1



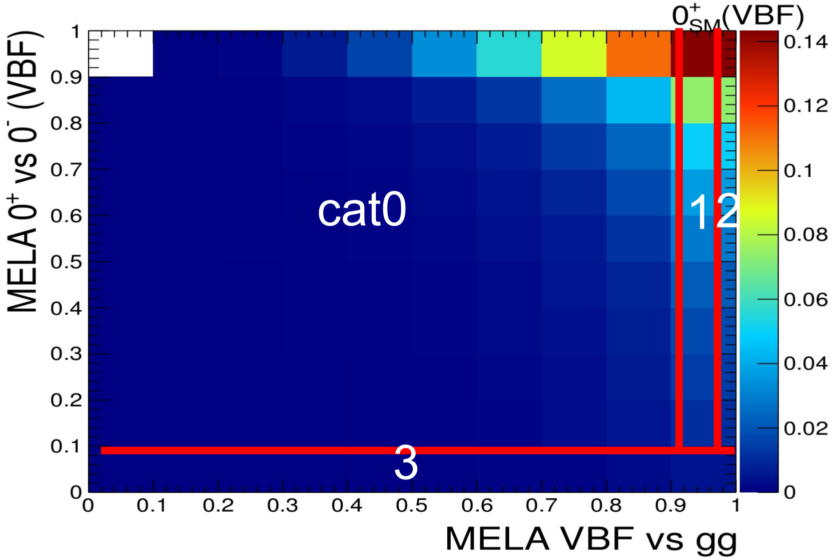


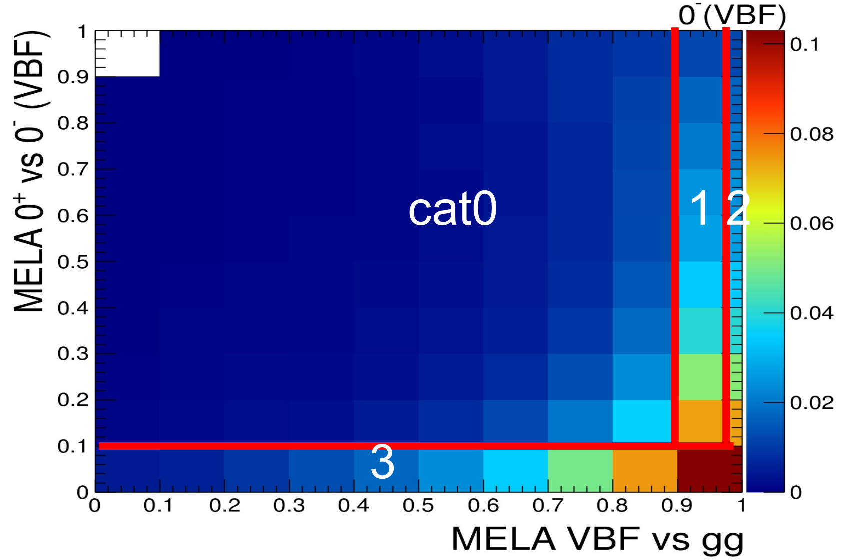
VBF 0- region

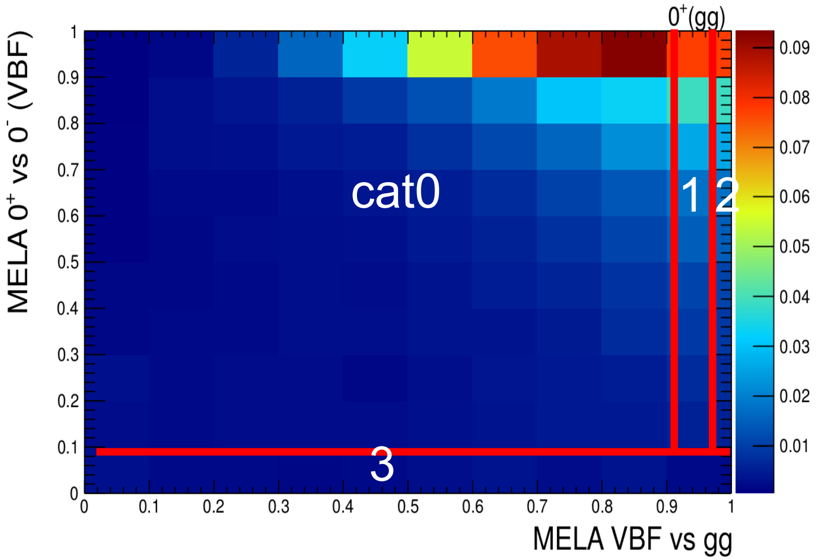


In each region extract Higgs signal yields from a fit to the diphoton mass
Allows to infer the yields due to the different productions: VBF(0+), VBF(0-), ggH

Categories optimisation



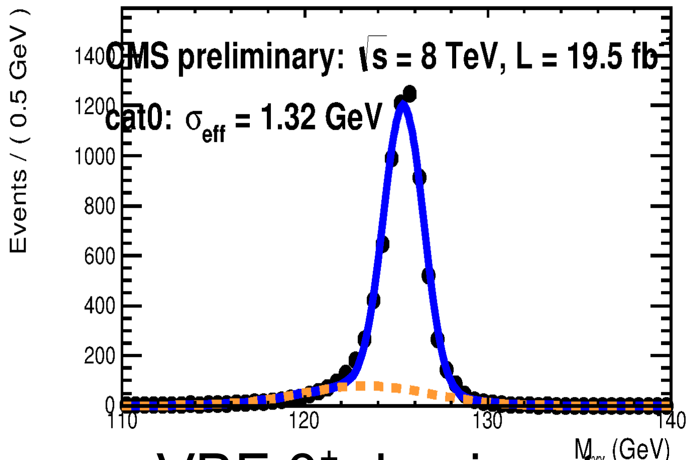




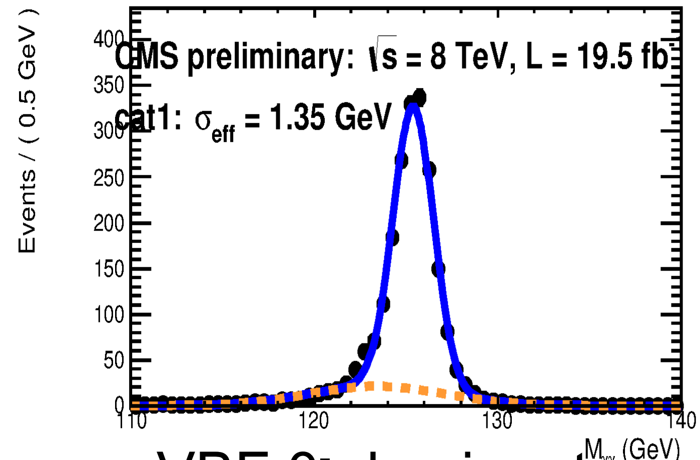
- 1D cuts on the two MELA discriminants optimised in order to have the best sensitivity
- Cuts combined in 2D to form optimised categories
- 4 categories at the end

Signal shapes, VBF 0^-

bkg dominant



VBF 0^+ dominant



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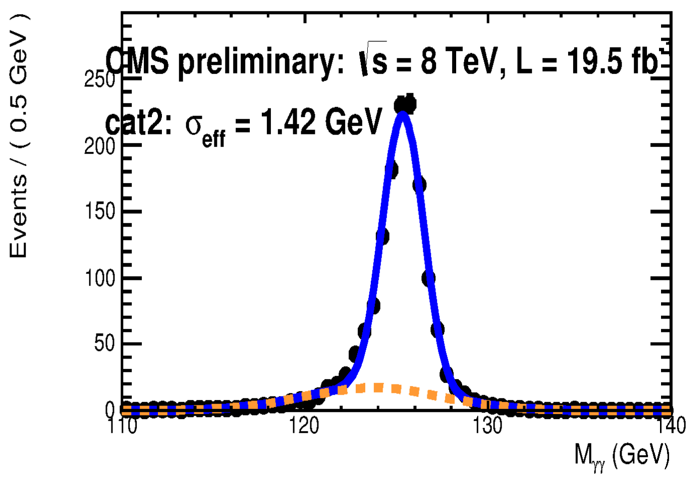
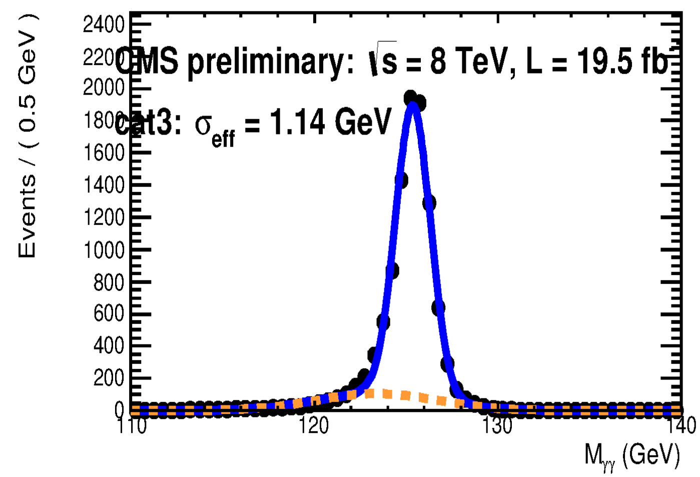
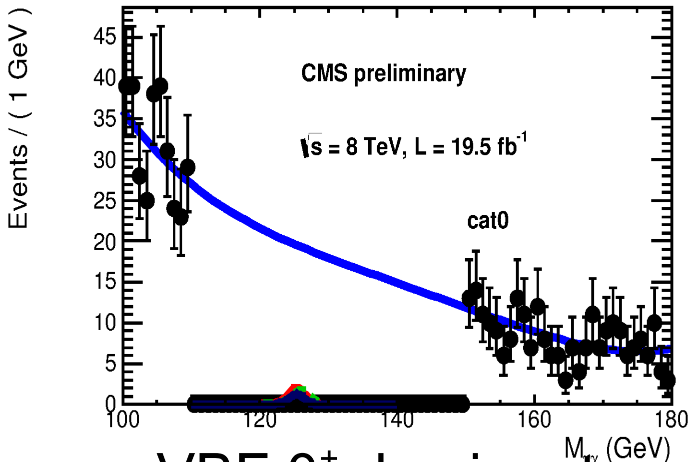


VBF 0^- dominant

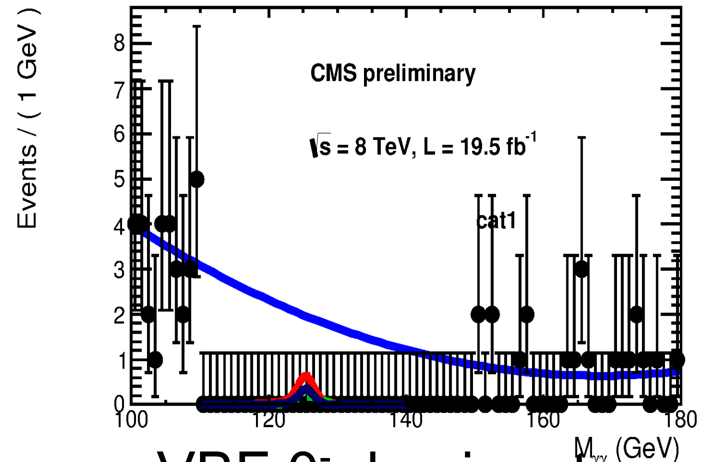


Background shapes

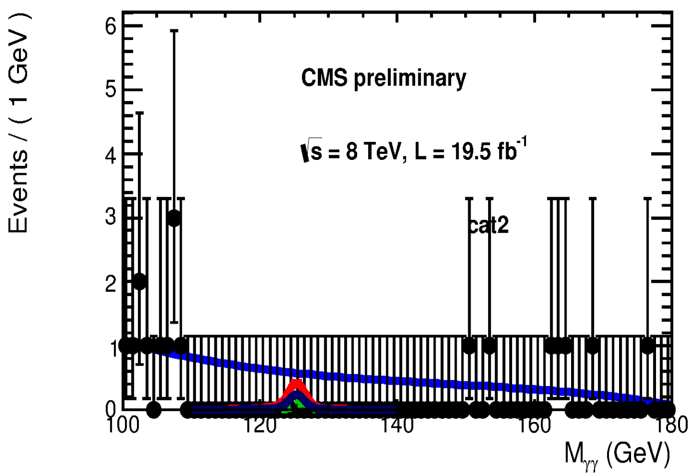
bkg dominant



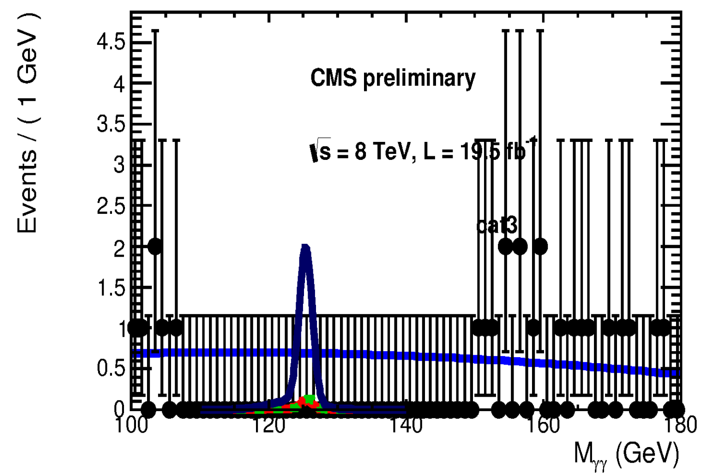
VBF 0+ dominant



VBF 0+ dominant



VBF 0- dominant



Conclusions and perspectives

- Involved in the preparation of the 13TeV data analysis
  - photon identification
  - development of analysis framework
  - in charge of $H\to\gamma\gamma$ simulated samples production
- First analysis of 13 TeV data for Higgs rediscovery
- HVV coupling analysis in VBF production using $H\to\gamma\gamma$ decay channel to be finalized (first with run 1 data)

Thanks for the attention !

Backup

HZZ results

H→ZZ sensibility:

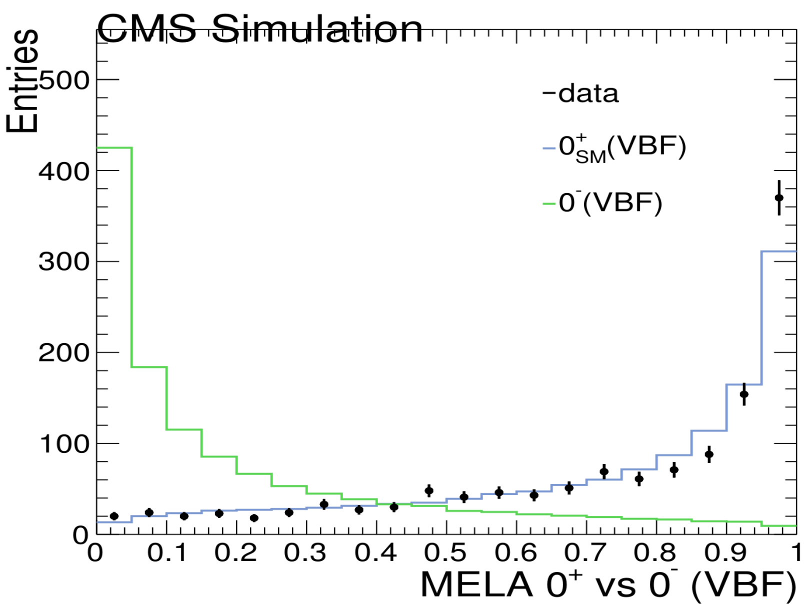
$$f_{a3}\ cos(\Phi_{a3}) \quad 0.00^{+0.33}_{-0.33}$$

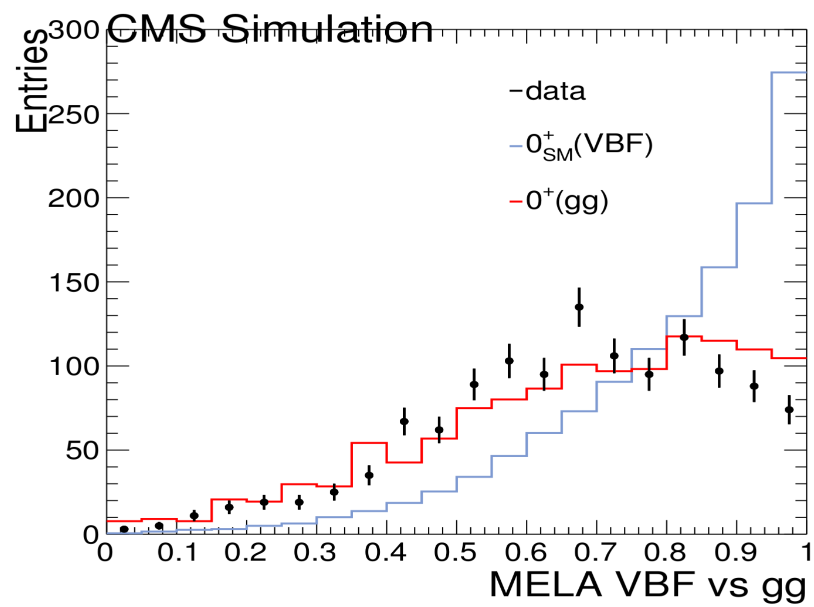
Expected sensibility for the VBF→H→γγ analysis:

~ a factor 2 less sensible

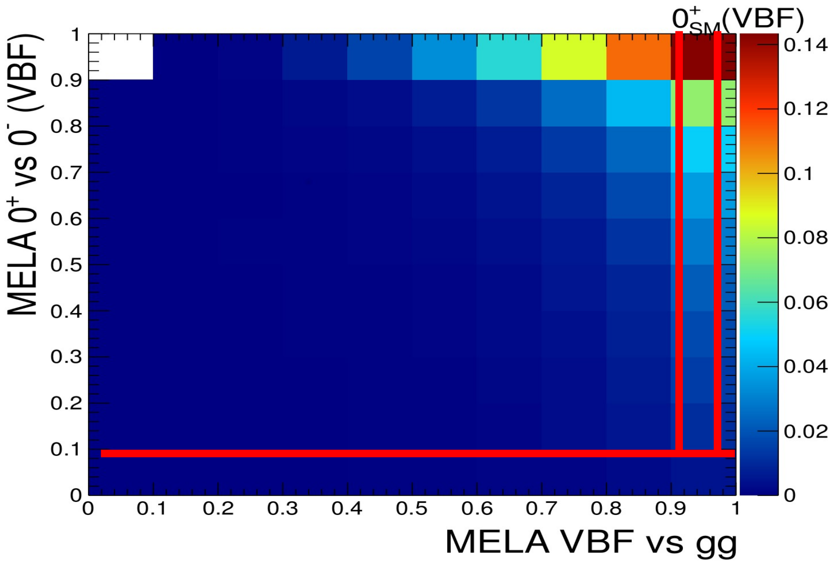
But important for the combination with other channels and for the new approach

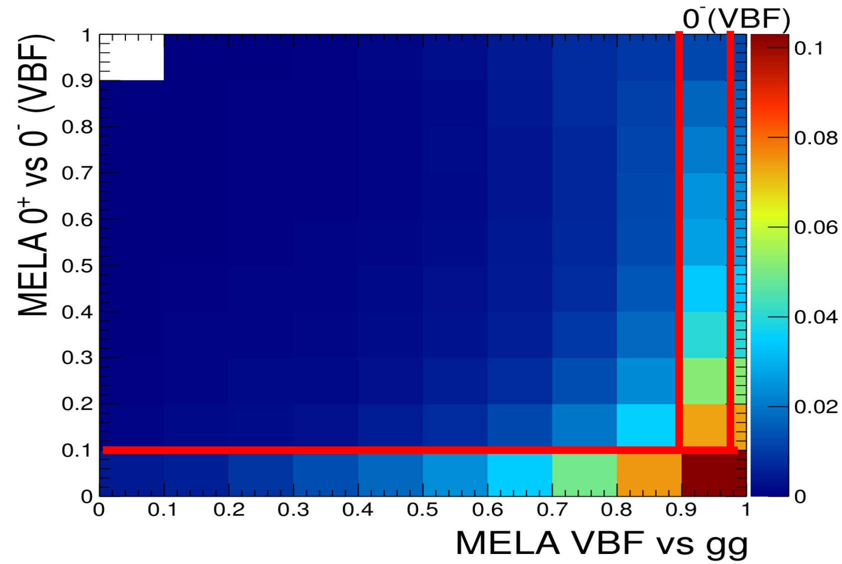
1D MELA histograms with data

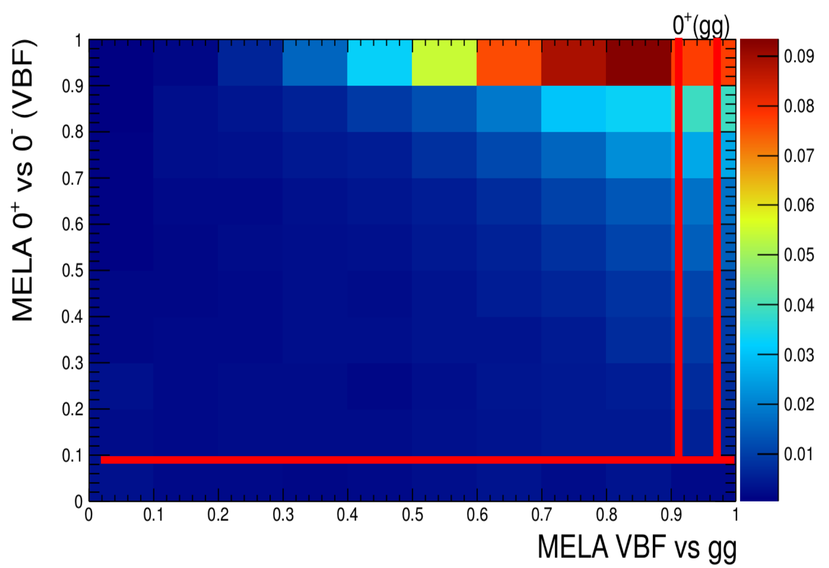


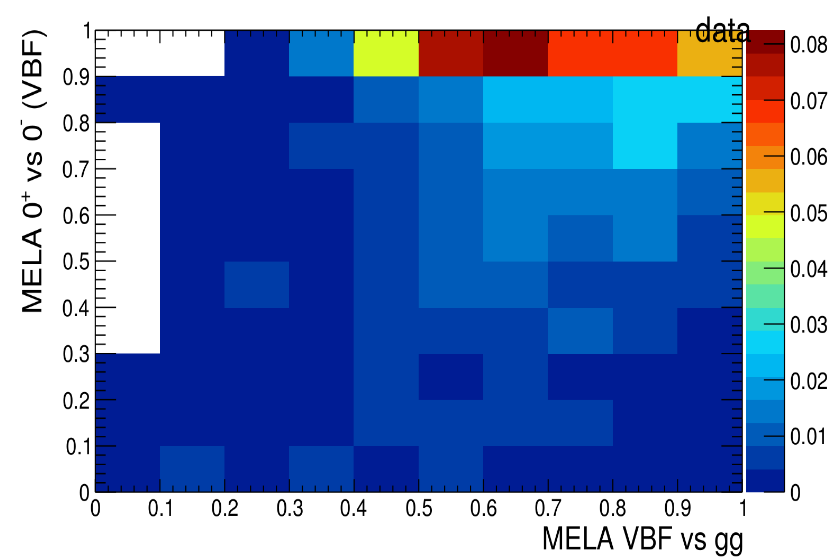


2D maps, added data









Interference study

Given Ai : acceptances due to VBF cuts

It is possible to define:

$$f = \frac{A_{0-}|a_3|^2\sigma_3}{A_{0+}|a_1|^2\sigma_1 + A_{0-}|a_3|^2\sigma_3}$$

Calculations show that the probability density corresponding to a 0+/0- mixed model with f_{a3} = 0.5 is:

$$P_{mix}(\vec{x}) = \frac{(1-f)P_{0+}(\vec{x}) \; + \; fP_{0-}(\vec{x}) \; + \; 2\sqrt{f(1-f)}I(\vec{x})}{1+2\sqrt{f(1-f)} \; \epsilon}$$

MELA discriminants

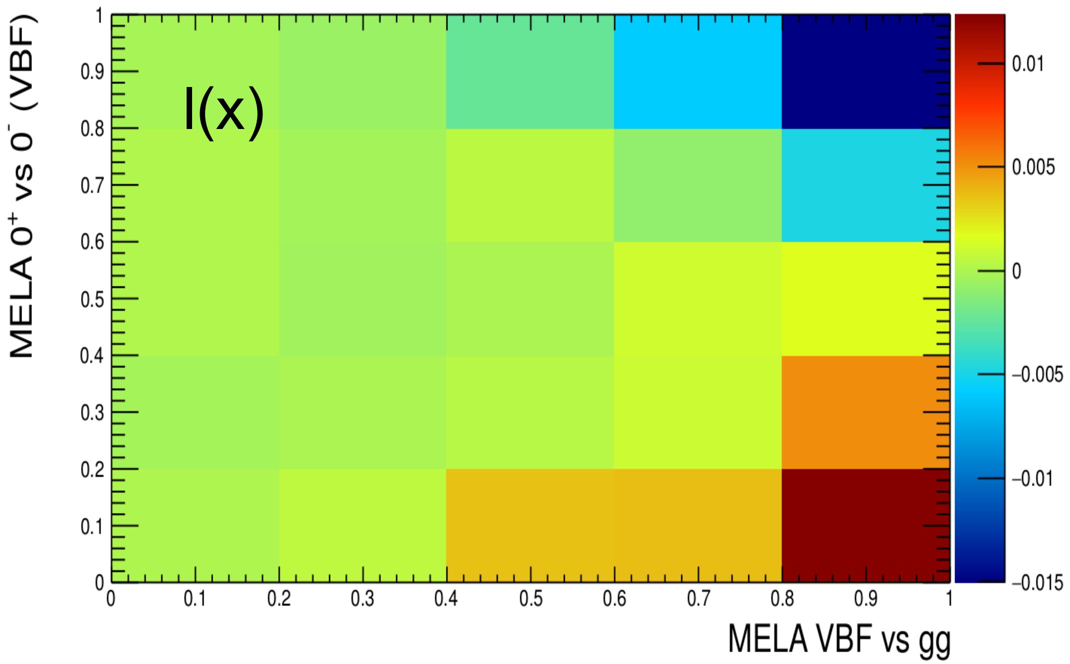
where:

$$\epsilon = \int I(\vec{x})\,\mathrm{d}x$$

ε very small ~ 0

Interference study

- three samples available: pure 0+, pure 0- and mixed with f_{a3} = 0.5
- the interference contribution I(x) is estimated using the mixed sample



$$\frac{|a_3|^2\sigma_3}{|a_1|^2\sigma_1+|a_3|^2\sigma_3} = 0.5$$

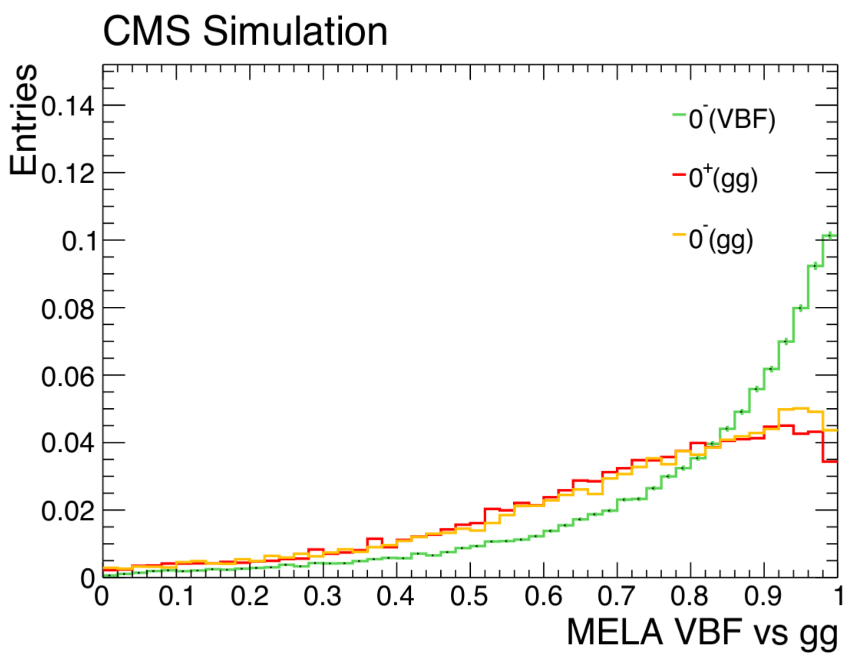
$\Phi_{a3} = 0$

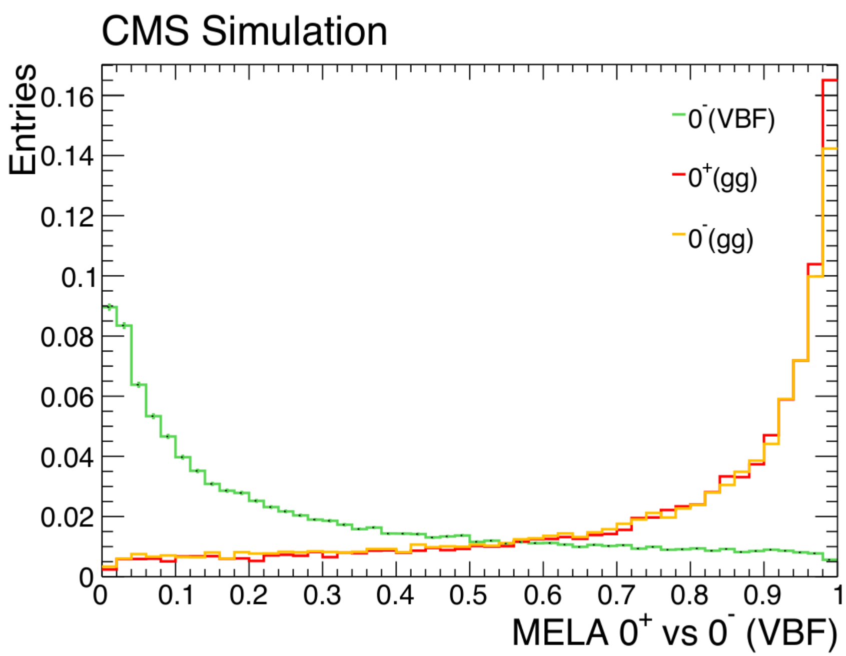
Conclusion: the interference term is negligible

Gluon fusion $0^+/0^-$ discrimination

$$D_{VBF} = \frac{P^{VBF}}{P^{VBF} + B \cdot P^{ggH}}$$

$$D_{0^-} = \frac{P^{VBF}}{P^{VBF} + C \cdot P^{VBF}_{0^-}}$$





The Physics Model

mass, category

Interference term neglected

$$f(x;\theta) =$$

VBF signal strength

pseudoscalar fraction related to fa3

$$\{\mu^{VBF}\ [\ (1 - r)\ f_{0+}^{VBF}(x;\theta) + r\ f_{0-}^{VBF}(x;\theta)\ ] +$$

$$\mu^{ggH}\ f^{ggH}(x;\theta)\ \} +$$

backgrounds

$$b\ f^{bkg}(x;\theta)$$